Chez Scheme Version 9.9.9-pre-release.20
User’s Guide
3.5. Locating objects  53
3.6. Nested object size and composition  54

4. Foreign Interface  57
4.1. Subprocess Communication  57
4.2. Calling out of Scheme  59
4.3. Calling into Scheme  70
4.4. Continuations and Foreign Calls  73
4.5. Foreign Data  74
4.6. Foreign Arrays of Managed Objects  90
4.7. Providing Access to Foreign Procedures  93
4.8. Using Other Foreign Languages  97
4.9. C Library Routines  97
4.10. Example: Socket Operations  109

5. Binding Forms  117
5.1. Definitions  117
5.2. Multiple-value Definitions  118
5.3. Recursive Bindings  119
5.4. Fluid Bindings  120
5.5. Top-Level Bindings  121

6. Control Structures  127
6.1. Conditionals  127
6.2. Mapping and Folding  129
6.3. Continuations  129
6.4. Engines  135
9. Input/Output Operations

9.1. Generic Ports
9.2. File Options
9.3. Transcoders
9.4. Port Operations
9.5. String Ports
9.6. File Ports
9.7. Custom Ports
9.8. Input Operations
9.9. Output Operations
9.10. Input/Output Operations
9.11. Non-Unicode Bytevector/String Conversions
9.12. Pretty Printing
9.13. Formatted Output
9.15. Fasl Output
9.16. File System Interface
9.17. Generic Port Examples

10. Libraries and Top-level Programs

10.1. Built-in Libraries
10.2. Running Top-level Programs
10.3. Library and Top-level Program Forms
10.4. Standalone import and export forms
10.5. Explicitly invoking libraries
10.6. Library Parameters
10.7. Library Inspection
11. Syntactic Extension and Modules 321

11.1. Fluid Keyword Bindings 321
11.2. Syntax-Rules Transformers 323
11.3. Syntax-Case Transformers 323
11.4. Compile-time Values and Properties 328
11.5. Modules 333
11.6. Standalone import and export forms 339
11.7. Built-in Modules 339
11.8. Meta Definitions 340
11.9. Conditional expansion 341
11.10. Aliases 342
11.11. Annotations 343
11.12. Source Tables 349

12. System Operations 353

12.1. Exceptions 353
12.2. Interrupts 357
12.3. Environments 361
12.4. Compilation, Evaluation, and Loading 364
12.5. Source Directories and Files 388
12.6. Compiler Controls 389
12.7. Profiling 397
12.8. Waiter Customization 407
12.9. Transcript Files 412
12.10. Times and Dates 413
12.11. Timing and Statistics 421
12.12. Cost Centers 427
12.13. Parameters 429
12.14. Virtual registers 431
12.15. Environmental Queries and Settings 432
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>References</td>
<td>493</td>
</tr>
<tr>
<td>Summary of Forms</td>
<td>497</td>
</tr>
<tr>
<td>Index</td>
<td>539</td>
</tr>
</tbody>
</table>
Chez Scheme is both a general-purpose programming language and an implementation of that language, with supporting tools and documentation. As a superset of the language described in the Revised\textsuperscript{6} Report on Scheme (R6RS), Chez Scheme supports all standard features of Scheme, including first-class procedures, proper treatment of tail calls, continuations, user-defined records, libraries, exceptions, and hygienic macro expansion. Chez Scheme supports numerous non-R6RS features. A few of these are local and top-level modules, local import, foreign datatypes and procedures, nonblocking I/O, an interactive top-level, compile-time values and properties, pretty-printing, and formatted output.

The implementation includes a compiler that generates native code for each processor upon which it runs along with a run-time system that provides automatic storage management, foreign-language interfaces, source-level debugging, profiling support, and an extensive runtime library.

The threaded versions of Chez Scheme support native threads, allowing Scheme programs to take advantage of multiprocessor or multiple-core systems. Nonthreaded versions are also available and are faster for single-threaded applications. Both 32-bit and 64-bit versions are available for some platforms. The 64-bit versions support larger heaps, while the 32-bit versions are faster for some applications.

Chez Scheme’s interactive programming system includes an expression editor that, like many shells, supports command-line editing, a history mechanism, and command completion. Unlike most shells that support command-line editing, the expression editor properly supports multiline expressions.

Chez Scheme is intended to be as reliable and efficient as possible, with reliability taking precedence over efficiency if necessary. Reliability means behaving as designed and documented. While a Chez Scheme program can always fail to work properly because of a bug in the program, it should never fail because of a bug in the Chez Scheme implementation. Efficiency means performing at a high level, consuming minimal CPU time and memory. Performance should be balanced across features, across run time and compile time, and across programs and data of different sizes. These principles guide Chez Scheme language and tool design as well as choice of implementation technique; for example, a language feature or debugging hook might not exist in Chez Scheme because its presence would reduce reliability, efficiency, or both.

The compiler has been rewritten for Version 9 and generates substantially faster code than the earlier compiler at the cost of greater compile time. This is the primary difference between Versions 8 and 9.
This book (CSUG) is a companion to *The Scheme Programming Language, 4th Edition* (TSPL4). TSPL4 serves as an introduction to and reference for R6RS, while CSUG describes *Chez Scheme* features and tools that are not part of R6RS. For the reader’s convenience, the summary of forms and index at the back of this book contain entries from both books, with each entry from TSPL4 marked with a “t” in front of its page number. In the online version, the page numbers given in the summary of forms and index double as direct links into one of the documents or the other.

Additional documentation for *Chez Scheme* includes release notes, a manual page, and a number of published papers and articles that describe various aspects of the system’s design and implementation.

Thank you for using *Chez Scheme*. 
1. Introduction

This book describes Chez Scheme extensions to the Revised\textsuperscript{6} Report on Scheme \cite{R6RS}. It contains as well a concise summary of standard and Chez Scheme forms and procedures, which gives the syntax of each form and the number and types of arguments accepted by each procedure. Details on standard R6RS features can be found in \textit{The Scheme Programming Language, 4th Edition} \cite{TSPL4} or the Revised\textsuperscript{6} Report on Scheme. \textit{The Scheme Programming Language, 4th Edition} also contains an extensive introduction to the Scheme language and numerous short and extended examples.

Most of this document also applies equally to Petite Chez Scheme, which is fully compatible with the complete Chez Scheme system but uses a high-speed interpreter in place of Chez Scheme’s incremental native-code compiler. Programs written for Chez Scheme run unchanged in Petite Chez Scheme as long as they do not require the compiler to be invoked. In fact, Petite Chez Scheme is built from the same sources as Chez Scheme, with all but the compiler sources included. A detailed discussion of the impact of this distinction appears in Section 2.8.

The remainder of this chapter covers Chez Scheme extensions to Scheme syntax (Section 1.1), notational conventions used in this book (Section 1.2), the use of parameters for system customization (Section 1.3), and where to look for more information on Chez Scheme (Section 1.4).

Chapter 2 describes how one uses Chez Scheme for program development, scripting, and application delivery, plus how to get the compiler to generate the most efficient code possible. Chapter 3 describes debugging and object inspection facilities. Chapter 4 documents facilities for interacting with separate processes or code written in other languages. Chapter 5 describes binding forms. Chapter 6 documents control structures. Chapter 7 documents operations on nonnumeric objects, while Chapter 8 documents various numeric operations, including efficient type-specific operations. Chapter 9 describes input/output operations and generic ports, which allow the definition of ports with arbitrary input/output semantics. Chapter 10 discusses how R6RS libraries and top-level programs are loaded into Chez Scheme along with various features for controlling and tracking the loading process. Chapter 11 describes syntactic extension and modules. Chapter 12 describes system operations, such as operations for interacting with the operating system and customizing Chez Scheme’s user interface. Chapter 13 describes how to invoke and control the storage management system and documents guardians and weak pairs. Chapter 14 describes Chez Scheme’s expression editor and how it can be customized. Chapter 15 documents the procedures and syntactic forms that comprise the interface to Chez Scheme’s native thread system. Finally, Chapter 16 describes various compatibility features.
The back of this book contains a bibliography, the summary of forms, and an index. The page numbers appearing in the summary of forms and the italicized page numbers appearing in the index indicate the locations in the text where forms and procedures are formally defined. The summary of forms and index includes entries from TSPL4, so that they cover the entire set of Chez Scheme features. A TSPL4 entry is marked by a “t” prefix on the page number.

Online versions and errata for this book and for TSPL4 can be found at www.scheme.com.

Acknowledgments: Michael Adams, Mike Ashley, Carl Bruggeman, Bob Burger, Sam Daniel, George Davidson, Matthew Flatt, Aziz Ghuloum, Bob Hieb, Andy Keep, and Oscar Waddell have contributed substantially to the development of Chez Scheme. Chez Scheme’s expression editor is based on a command-line editor for Scheme developed from 1989 through 1994 by C. David Boyer. File compression is performed with the use of the lz4 compression library developed by Yann Collet or the zlib compression library developed by Jean-loup Gailly and Mark Adler. Implementations of the list and vector sorting routines are based on Olin Shiver’s opportunistic merge-sort algorithm and implementation. Michael Lenaghan provided a number of corrections for earlier drafts of this book. Many of the features documented in this book were suggested by current Chez Scheme users, and numerous comments from users have also led to improvements in the text. Additional suggestions for improvements to Chez Scheme and to this book are welcome.

1.1. Chez Scheme Syntax

Chez Scheme extends Scheme’s syntax both at the object (datum) level and at the level of syntactic forms. At the object level, Chez Scheme supports additional representations for symbols that contain nonstandard characters, nondecimal numbers expressed in floating-point and scientific notation, vectors with explicit lengths, shared and cyclic structures, records, boxes, and more. These extensions are described below. Form-level extensions are described throughout the book and summarized in the Summary of Forms, which also appears in the back of this book.

Chez Scheme extends the syntax of identifiers in several ways. First, the sequence of characters making up an identifier’s name may start with digits, periods, plus signs, and minus signs as long as the sequence cannot be parsed as a number. For example, 0abc, ++++, and .. are all valid identifiers in Chez Scheme. Second, the single-character sequences { and } are identifiers. Third, identifiers containing arbitrary characters may be printed by escaping them with \ or with |. \ is used to escape a single character (except ’x’, since ’x’ marks the start of a hex scalar value), whereas | is used to escape the group of characters that follow it up through the matching |. For example, |\|\| is an identifier with a two-character name consisting of the character \ followed by the character \, and |hit me!!| is an identifier whose name contains a space.

In addition, gensyms (page 7.11) are printed with #\ and } brackets that enclose both the “pretty” and “unique” names, e.g., #\{g1426 e5g1c94g642dssw-a\}. They may also be printed using the pretty name only with the prefix #:, e.g., #:g1426.
Arbitrary radixes from two through 36 may be specified with the prefix \#n_{r}, where \( n \) is the radix. Case is not significant, so \#nR may be used as well. Digit values from 10 through 35 are specified as either lower- or upper-case alphabetic characters, just as for hexadecimal numbers. For example, \#36rZZ is \( 35 \times 36 + 35 \), or 1295.

Chez Scheme also permits nondecimal numbers to be printed in floating-point or scientific notation. For example, \#o1.4 is equivalent to 1.5, and \#b1e10 is equivalent to 4.0. Digits take precedence over exponent specifiers, so that \#x1e20 is simply the four-digit hexadecimal number equivalent to 7712.

In addition to the standard named characters \#\{alarm, backspace, delete, esc, linefeed, newline, page, return, space, and tab, Chez Scheme recognizes \#\{bel, ls, nel, nul, rubout, and vt (or vtab). Characters whose scalar values are less than 256 may also be printed with an octal syntax consisting of the prefix \# followed by a three octal-digit sequence. For example, \#\{000 is equivalent to \#\{nul.

Chez Scheme’s fxvectors, or fixnum vectors, are printed like vectors but with the prefix \#\{vfx( in place of \#( . Similarly, flvectors, or flonum vectors, are printed with the prefix \#\{vfl(, and stencil vectors with the prefix \#\{nvs( . Vectors, bytevectors, fxvectors, and flvectors may be printed with an explicit length prefix, and when the explicit length prefix is specified, duplicate trailing elements may be omitted. For example, \#(a b c) may be printed as \#3(a b c), and a vector of length 100 containing all zeros may be printed as \#100(0). Stencil vectors have a mask rather than an explicit length prefix, and it is always included in the printed representation.

Chez Scheme’s boxes are printed with a \#\{ prefix, e.g., \#\{17 is a box containing the integer 17.

Records are printed with the syntax \#\{[type-name field ...], where the symbol type-name is the name of the record type and field ... are the printed representations for the contents of the fields of the record.

Shared and cyclic structure may be printed using the graph mark and reference prefixes \#n= and \#n#. \#n= is used to mark an item in the input, and \#n# is used to refer to the item marked \( n \). For example, '('#1=(a) . #1#) is a pair whose car and cdr contain the same list, and '#0=(a . #0#) is a cyclic list, i.e., its cdr is itself.

A \$\{primitive form (see page 390) may be abbreviated in the same manner as a quote form, using the \#\% prefix. For example, \#\%car is equivalent to \($\{primitive car\), \#2\%car to \($\{primitive 2 car\), and \#3\%car to \($\{primitive 3 car\).

Chez Scheme’s end-of-file object is printed \#!eof. If the end-of-file object appears outside of any datum within a file being loaded, load will treat it as if it were a true end of file and stop loading at that point. Inserting \#!eof into the middle of a file can thus be handy when tracking down a load-time error.

Broken pointers in weak pairs (see page 443) are represented by the broken weak pointer object, which is printed \#!bwp.

In addition to the standard delimiters (whitespace, open and close parentheses, open and close brackets, double quotes, semi-colon, and #), Chez Scheme also treats as delimiters open and close braces, single quote, backward quote, and comma.
Finally, Chez Scheme accepts #true and #false as alternative spellings of the booleans #t and #f. Like the external representation of numbers, case is not significant; for example, #T, #True and #TRUE are all equivalent.

The Chez Scheme lexical extensions described above are disabled in an input stream after an #!r6rs comment directive has been seen, unless a #!chezscheme comment directive has been seen since. Each library loaded implicitly via import and each RNRS top-level program loaded via the --program command-line option, the scheme-script command, or the load-program procedure is treated as if it begins implicitly with an #!r6rs comment directive.

The case of symbol and character names is normally significant, as required by the Revised\textsuperscript{6} Report. Names are folded, as if by string-foldcase, following a #!fold-case comment directive in the same input stream unless a #!no-fold-case has been seen since. Names are also folded if neither directive has been seen and the parameter case-sensitive has been set to #f.

The printer invoked by write, put-datum, pretty-print, and the format -s option always prints standard Revised\textsuperscript{6} Report objects using the standard syntax, unless a different behavior is requested via the setting of one of the print parameters. For example, it prints symbols in the extended identifier syntax of Chez Scheme described above using hex scalar value escapes, unless the parameter print-extended-identifiers is set to true. Similarly, it does not print the explicit length or suppress duplicate trailing elements unless the parameter print-vector-length is set to true.

### 1.2. Notational Conventions

This book follows essentially the same notational conventions as The Scheme Programming Language, 4th Edition. These conventions are repeated below, with notes specific to Chez Scheme.

When the value produced by a procedure or syntactic form is said to be unspecified, the form or procedure may return any number of values, each of which may be any Scheme object. Chez Scheme usually returns a single, unique void object (see void) whenever the result is unspecified; avoid counting on this behavior, however, especially if your program may be ported to another Scheme implementation. Printing of the void object is suppressed by Chez Scheme’s waiter (read-evaluate-print loop).

This book uses the words “must” and “should” to describe program requirements, such as the requirement to provide an index that is less than the length of the vector in a call to vector-ref. If the word “must” is used, it means that the requirement is enforced by the implementation, i.e., an exception is raised, usually with condition type &assertion. If the word “should” is used, an exception may or may not be raised, and if not, the behavior of the program is undefined. The phrase “syntax violation” is used to describe a situation in which a program is malformed. Syntax violations are detected prior to program execution. When a syntax violation is detected, an exception of type &syntax is raised and the program is not executed.
1.3. Parameters

Scheme objects are displayed in a *typewriter* typeface just as they are to be typed at the keyboard. This includes identifiers, constant objects, parenthesized Scheme expressions, and whole programs. An *italic* typeface is used to set off syntax variables in the descriptions of syntactic forms and arguments in the descriptions of procedures. Italics are also used to set off technical terms the first time they appear. The first letter of an identifier that is not ordinarily capitalized is not capitalized when it appears at the beginning of a sentence. The same is true for syntax variables written in italics.

In the description of a syntactic form or procedure, a pattern shows the syntactic form or the application of the procedure. The syntax keyword or procedure name is given in typewriter font, as are parentheses. The remaining pieces of the syntax or arguments are shown in italics, using names that imply the types of the expressions or arguments expected by the syntactic form or procedure. Ellipses are used to specify zero or more occurrences of a subexpression or argument.

1.3. Parameters

All *Chez Scheme* system customization is done via *parameters*. A parameter is a procedure that encapsulates a hidden state variable. When invoked without arguments, a parameter returns the value of the encapsulated variable. When invoked with one argument, the parameter changes the value of the variable to the value of its argument. A parameter may raise an exception if its argument is not appropriate, or it may filter the argument in some way.

New parameters may be created and used by programs running in *Chez Scheme*. Parameters are used rather than global variables for program customization for two reasons: First, unintentional redefinition of a customization variable can cause unexpected problems, whereas unintentional redefinition of a parameter simply makes the parameter inaccessible. For example, a program that defines *print-level* for its own purposes in early releases of *Chez Scheme* would have unexpected effects on the printing of Scheme objects, whereas a program that defines print-level for its own purposes simply loses the ability to alter the printer’s behavior. Of course, a program that invokes print-level by accident can still affect the system in unintended ways, but such an occurrence is less likely, and can only happen in an incorrect program.

Second, invalid values for parameters can be detected and rejected immediately when the “assignment” is made, rather than at the point where the first use occurs, when it is too late to recover and reinstate the old value. For example, an assignment of *print-level* to −1 would not have been caught until the first call to write or pretty-print, whereas an attempted assignment of −1 to the parameter print-level, i.e., (print-level -1), is flagged as an error immediately, before the change is actually made.

Built-in system parameters are described in different sections throughout this book and are listed along with other syntactic forms and procedures in the Summary of Forms in the back of this book. Parameters marked “thread parameters” have per-thread values in threaded versions of *Chez Scheme*, while the values of parameters marked “global parameters” are shared by all threads. Nonthreaded versions of *Chez Scheme* do not distinguish between
thread and global parameters. See Sections 12.13 and 15.8 for more information on creating and manipulating parameters.

1.4. More Information

The articles and technical reports listed below document various features of Chez Scheme and its implementation:

- syntactic abstraction [14, 8, 17],
- modules [32],
- libraries [21],
- storage management [12, 13],
- threads [10],
- multiple return values [2],
- optional arguments [16],
- continuations [7, 25, 8],
- eq? hash-tables [20],
- internal definitions, letrec, and letrec* [33, 22],
- equal? [1],
- engines [15],
- floating-point printing [4],
- code generation [18],
- register allocation [6],
- procedure inlining [31],
- profiling [5], and
- history of the implementation [9].

Links to abstracts and electronic versions of these publications are available at the url http://www.cs.indiana.edu/chezscheme/pubs/
2. Using Chez Scheme

Chez Scheme is often used interactively to support program development and debugging, yet it may also be used to create stand-alone applications with no interactive component. This chapter describes the various ways in which Chez Scheme is typically used and, more generally, how to get the most out of the system. Sections 2.1, 2.2, and 2.3 describe how one uses Chez Scheme interactively. Section 2.4 discusses how libraries and RNRS top-level programs are used in Chez Scheme. Section 2.5 covers support for writing and running Scheme scripts, including compiled scripts and compiled RNRS top-level programs. Section 2.6 describes how to structure and compile an application to get the most efficient code possible out of the compiler. Section 2.7 describes how one can customize the startup process, e.g., to alter or eliminate the command-line options, to preload Scheme or foreign code, or to run Chez Scheme as a subordinate program of another program. Section 2.8 describes how to build applications using Chez Scheme with Petite Chez Scheme for run-time support. Finally, Section 2.9 covers command-line options used when invoking Chez Scheme.

2.1. Interacting with Chez Scheme

One of the simplest and most effective ways to write and test Scheme programs is to compose them using a text editor, like vi or emacs, and test them interactively with Chez Scheme running in a shell window. When Chez Scheme is installed with default options, entering the command scheme at the shell’s prompt starts an interactive Scheme session. The command petite does the same for Petite Chez Scheme. After entering this command, you should see a short greeting followed by an angle-bracket on a line by itself, like this:

Chez Scheme Version 9.5.1
Copyright 1984-2017 Cisco Systems, Inc.

> 

You also should see that the cursor is sitting one space to the right of the angle-bracket. The angle-bracket is a prompt issued by the system’s “REPL,” which stands for “Read Eval Print Loop,” so called because it reads, evaluates, and prints an expression, then loops back to read, evaluate, and print the next, and so on. (In Chez Scheme, the REPL is also called a waiter.)
In response to the prompt, you can type any Scheme expression. If the expression is well-formed, the REPL will run the expression and print the value. Here are a few examples:

> 3
3
> (+ 3 4)
7
> (cons 'a '(b c d))
(a b c d)

The reader used by the REPL is more sophisticated than an ordinary reader. In fact, it’s a full-blown “expression editor” (“expeditor” for short) like a regular text editor but for just one expression at a time. One thing you might soon notice is that the system automatically indents the second and subsequent lines of an expression. For example, let’s say we want to define fact, a procedure that implements the factorial function. If we type (define fact followed by the enter key, the cursor should be sitting under the first e in define, so that if we then type (lambda (x), we should see:

> (define fact
 (lambda (x)

The expeditor also allows us to move around within the expression (even across lines) and edit the expression to correct mistakes. After typing:

> (define fact
 (lambda (x)
   (if (= n 0)
    0
    (* n (fact

we might notice that the procedure’s argument is named x but we have been referencing it as n. We can move back to the second line using the arrow keys, remove the offending x with the backspace key, and replace it with n.

> (define fact
 (lambda (n)
   (if (= n 0)
    0
    (* n (fact

We can then return to the end of the expression with the arrow keys and complete the definition.

> (define fact
 (lambda (n)
   (if (= n 0)
    0
    (* n (fact (- n 1))))))

Now that we have a complete form with balanced parentheses, if we hit enter with the
cursor just after the final parenthesis, the expeditor will send it on to the evaluator. We’ll know that it has accepted the definition when we get another right-angle prompt.

Now we can test our definition by entering, say, \((\text{fact 6})\) in response to the prompt:

\[
(\text{fact 6})
\]

0

The printed value isn’t what we’d hoped for, since 6! is actually 720. The problem, of course, is that the base-case return-value 0 should have been 1. Fortunately, we don’t have to retype the definition to correct the mistake. Instead, we can use the expeditor’s history mechanism to retrieve the earlier definition. The up-arrow key moves backward through the history. In this case, the first up-arrow retrieves \((\text{fact 6})\), and the second retrieves the \text{fact} definition.

As we move back through the history, the expression editor shows us only the first line, so after two up arrows, this is all we see of the definition:

\[
(\text{define fact}
\]

We can force the expeditor to show the entire expression by typing \(^L\) (control L, i.e., the control and L keys pressed together):

\[
(\text{define fact}
\quad (\text{lambda (n)}
\quad \quad (\text{if (= n 0)}
\quad \quad \quad 0
\quad \quad \quad (* n (\text{fact (- n 1)})))))
\]

Now we can move to the fourth line and change the 0 to a 1.

\[
(\text{define fact}
\quad (\text{lambda (n)}
\quad \quad (\text{if (= n 0)}
\quad \quad \quad 1
\quad \quad \quad (* n (\text{fact (- n 1)})))))
\]

We’re now ready to enter the corrected definition. If the cursor is on the fourth line and we hit enter, however, it will just open up a new line between the old fourth and fifth lines. This is useful in other circumstances, but not now. Of course, we can work around this by using the arrow keys to move to the end of the expression, but an easier way is to type \(^J\), which forces the expression to be entered immediately no matter where the cursor is.

Finally, we can bring back \((\text{fact 6})\) with another two hits of the up-arrow key and try it again:

\[
(\text{fact 6})
\]

720

To exit from the REPL and return back to the shell, we can type \(^D\) or call the \text{exit} procedure.
The interaction described above uses just a few of the expeditor’s features. The expeditor’s remaining features are described in the following section.

Running programs may be interrupted by typing the interrupt character (typically \texttt{\textasciicircum C}). In response, the system enters a debug handler, which prompts for input with a \texttt{break>} prompt. One of several commands may be issued to the break handler (followed by a newline), including

- \texttt{“e”} or end-of-file to exit from the handler and continue,
- \texttt{“r”} to stop execution and reset to the current café,
- \texttt{“a”} to abort \textit{Chez Scheme},
- \texttt{“n”} to enter a new café (see below),
- \texttt{“i”} to inspect the current continuation,
- \texttt{“s”} to display statistics about the interrupted program, and
- \texttt{“?”} to display a list of these options.

When an exception other than a warning occurs, the default exception handler prints a message that describes the exception to the console error port. If a REPL is running, the exception handler then returns to the REPL, where the programmer can call the \texttt{debug} procedure to start up the debug handler, if desired. The debug handler is similar to the break handler and allows the programmer to inspect the continuation (control stack) of the exception to help determine the cause of the problem. If no REPL is running, as is the case for a script or top-level program run via the --script or --program command-line options, the default exception handler exits from the script or program after printing the message. To allow scripts and top-level programs to be debugged, the default exception handler can be forced via the \texttt{debug-on-exception} parameter or the \texttt{--debug-on-exception} command-line option to invoke \texttt{debug} directly.

Developing a large program entirely in the REPL is unmanageable, and we usually even want to store smaller programs in a file for future use. (The expeditor’s history is saved across Scheme sessions, but there is a limit on the number of items, so it is not a good idea to count on a program remaining in the history indefinitely.) Thus, a Scheme programmer typically creates a file containing Scheme source code using a text editor, such as \texttt{vi}, and loads the file into \textit{Chez Scheme} to test them. The conventional filename extension for \textit{Chez Scheme} source files is \texttt{“.ss,”} but the file can have any extension or even no extension at all. A source file can be loaded during an interactive session by typing \texttt{(load “path”).} Files to be loaded can also be named on the command line when the system is started. Any form that can be typed interactively can be placed in a file to be loaded.

\textit{Chez Scheme} compiles source forms as it sees them to machine code before evaluating them, i.e., “just in time.” In order to speed loading of a large file or group of files, each file can be compiled ahead of time via \texttt{compile-file}, which puts the compiled code into a separate object file. For example, \texttt{(compile-file “path”)} compiles the forms in the file \texttt{path.ss} and places the resulting object code in the file \texttt{path.so}. Loading a pre-compiled file is essentially no different from loading the source file, except that loading is faster since compilation has already been done.
2.2. Expression Editor

When compiling a file or set of files, it is often more convenient to use a shell command than to enter Chez Scheme interactively to perform the compilation. This is easily accomplished by “piping” in the command to compile the file as shown below.

```
echo '(compile-file "filename")' | scheme -q
```

The `--q` option suppresses the system’s greeting messages for more compact output, which is especially useful when compiling numerous files. The single-quote marks surrounding the `compile-file` call should be left off for Windows shells.

When running in this “batch” mode, especially from within “make” files, it is often desirable to force the default exception handler to exit immediately to the shell with a nonzero exit status. This may be accomplished by setting the `reset-handler` to `abort`.

```
echo '(reset-handler abort) (compile-file "filename")' | scheme -q
```

One can also redefine the `base-exception-handler` (Section 12.1) to achieve a similar effect while exercising more control over the format of the messages that are produced.

2.2. Expression Editor

When Chez Scheme is used interactively in a shell window, as described above, or when `new-cafe` is invoked explicitly from a top-level program or script run via `--program` or `--script`, the waiter’s “prompt and read” procedure employs an expression editor that permits entry and editing of single- and multiple-line expressions, automatically indents expressions as they are entered, supports identifier completion outside string constants based on the identifiers defined in the interactive environment, and supports filename completion within string constants. The expression editor also maintains a history of expressions typed during and across sessions and supports tcsh-like history movement and search commands. Other editing commands include simple cursor movement via arrow keys, deletion of characters via backspace and delete, and movement, deletion, and other commands using mostly emacs key bindings.

The expression editor does not run if the TERM environment variable is not set (on Unix-based systems), if the standard input or output files have been redirected, or if the `--edisable` command-line option (Section 2.9) has been used. The history is saved across sessions, by default, in the file “.chezscheme.history” in the user’s home directory. The `--ehistory` command-line option (Section 2.9) can be used to specify a different location for the history file or to disable the saving and restoring of the history file.

Keys for nearly all printing characters (letters, digits, and special characters) are “self inserting” by default. The open parenthesis, close parenthesis, open bracket, and close bracket keys are self inserting as well, but also cause the editor to “flash” to the matching delimiter, if any. Furthermore, when a close parenthesis or close bracket is typed, it is automatically corrected to match the corresponding open delimiter, if any.

Key bindings for other keys and key sequences initially recognized by the expression editor are given below, organized into groups by function. Some keys or key sequences serve more
than one purpose depending upon context. For example, tab is used for identifier comple-
tion, filename completion, and indentation. Such bindings are shown in each applicable
functional group.

Multiple-key sequences are displayed with hyphens between the keys of the sequences, but
these hyphens should not be entered. When two or more key sequences perform the same
operation, the sequences are shown separated by commas.

Detailed descriptions of the editing commands are given in Chapter 14 which also describes
parameters that allow control over the expression editor, mechanisms for adding or changing
key bindings, and mechanisms for creating new commands.

Newlines, acceptance, exiting, and redisplay:
- `enter, ^M`: accept balanced entry if used at end of entry;
  else add a newline before the cursor and indent
- `^J`: accept entry unconditionally
- `^O`: insert newline after the cursor and indent
- `^D`: exit from the waiter if entry is empty;
  else delete character under cursor
- `^Z`: suspend to shell if shell supports job control
- `^L`: redisplay entry
- `^L-L`: clear screen and redisplay entry

Basic movement and deletion:
- `leftarrow, ^B`: move cursor left
- `rightarrow, ^F`: move cursor right
- `uparrow, ^P`: move cursor up; from top of unmodified entry,
  move to preceding history entry.
- `downarrow, ^N`: move cursor down; from bottom of unmodified entry,
  move to next history entry
- `^D`: delete character under cursor if entry not empty,
  else exit from the waiter
- `backspace, ^H`: delete character before cursor
- `delete`: delete character under cursor

Line movement and deletion:
- `home, ^A`: move cursor to beginning of line
- `end, ^E`: move cursor to end of line
- `^K, esc-k`: delete to end of line or, if cursor is at the end
  of a line, join with next line
- `^U`: delete contents of current line

When used on the first line of a multiline entry of which only the first line is displayed,
i.e., immediately after history movement, `^U` deletes the contents of the entire entry, like
`^G` (described below).
Expression movement and deletion:

- `esc-^F` move cursor to next expression
- `esc-^B` move cursor to preceding expression
- `esc-J` move cursor to matching delimiter
- `^J` flash cursor to matching delimiter
- `esc-^K, esc-delete` delete next expression
- `esc-backspace, esc-^H` delete preceding expression

Entry movement and deletion:

- `esc-<` move cursor to beginning of entry
- `esc->` move cursor to end of entry
- `^G` delete current entry contents
- `^C` delete current entry contents; reset to end of history

Indentation:

- `tab` re-indent current line if identifier/filename prefix not just entered; else insert completion
- `esc-tab` re-indent current line unconditionally
- `esc-q, esc-Q, esc-^Q` re-indent each line of entry

Identifier/filename completion:

- `tab` insert completion if identifier/filename prefix just entered; else re-indent current line
- `tab-tab` show possible identifier/filename completions at end of identifier/filename just typed, else re-indent
- `^R` insert next identifier/filename completion

Identifier completion is performed outside of a string constant, and filename completion is performed within a string constant. (In determining whether the cursor is within a string constant, the expression editor looks only at the current line and so can be fooled by string constants that span multiple lines.) If at end of existing identifier or filename, i.e., not one just typed, the first tab re-indents, the second tab inserts identifier completion, and the third shows possible completions.

History movement:

- `uparrow, ^P` move to preceding entry if at top of unmodified entry; else move up within entry
- `downarrow, ^N` move to next entry if at bottom of unmodified entry; else move down within entry
- `esc-uparrow, esc-^P` move to preceding entry from unmodified entry
- `esc-downarrow, esc-^N` move to next entry from unmodified entry
- `esc-p` search backward through history for given prefix
- `esc-n` search forward through history for given prefix
- `esc-P` search backward through history for given string
- `esc-N` search forward through history for given string

To search, enter a prefix or string followed by one of the search key sequences. Follow with additional search key sequences to search further backward or forward in the history. For
example, enter "(define" followed by one or more esc-p key sequences to search backward for entries that are definitions, or "(define" followed by one or more esc-P key sequences for entries that contain definitions.

Word and page movement:

- `esc-f, esc-F` move cursor to end of next word
- `esc-b, esc-B` move cursor to start of preceding word
- `^X-[` move cursor up one screen page
- `^X-` move cursor down one screen page

Inserting saved text:

- `^Y` insert most recently deleted text
- `^V` insert contents of window selection/paste buffer

Mark operations:

- `^@, ^space, ^^` set mark to current cursor position
- `^X-^X` move cursor to mark, leave mark at old cursor position
- `^W` delete between current cursor position and mark

Command repetition:

- `esc-^U` repeat next command four times
- `esc-^U-n` repeat next command n times

2.3. The Interaction Environment

In the language of the Revised^6^ Report, code is structured into libraries and “top-level programs.” The Revised^6^ Report does not require an implementation to support interactive use, and it does not specify how an interactive top level should operate, leaving such details up to the implementation.

In *Chez Scheme*, when one enters definitions or expressions at the prompt or loads them from a file, they operate on an interaction environment, which is a mutable environment that initially holds bindings only for built-in keywords and primitives. It may be augmented by user-defined identifier bindings via top-level definitions. The interaction environment is also referred to as the top-level environment, because it is at the top level for purposes of scoping. Programs entered at the prompt or loaded from a file via `load` should not be confused with RNRS top-level programs, which are actually more similar to libraries in their behavior. In particular, while the same identifier can be defined multiple times in the interaction environment, to support incremental program development, an identifier can be defined at most once in an RNRS top-level program.

The default interaction environment used for any code that occurs outside of an RNRS top-level program or library (including such code typed at a prompt or loaded from a file) contains all of the bindings of the `(chezscheme)` library (or `scheme` module, which exports the same set of bindings). This set contains a number of bindings that are not in the RNRS libraries. It also contains a number of bindings that extend the RNRS counterparts in some way and are thus not strictly compatible with the RNRS bindings for the same
identifiers. To replace these with bindings strictly compatible with RNRS, simply import the rnrs libraries into the interaction environment by typing the following into the REPL or loading it from a file:

(import
  (rnrs)
  (rnrs eval)
  (rnrs mutable-pairs)
  (rnrs mutable-strings)
  (rnrs r5rs))

To obtain an interaction environment that contains all and only RNRS bindings, use the following.

(interaction-environment
  (copy-environment
    (environment
      '(rnrs)
      '(rnrs eval)
      '(rnrs mutable-pairs)
      '(rnrs mutable-strings)
      '(rnrs r5rs)
      #t))

To be useful for most purposes, library and import should probably also be included, from the (chezscheme) library.

(interaction-environment
  (copy-environment
    (environment
      '(rnrs)
      '(rnrs eval)
      '(rnrs mutable-pairs)
      '(rnrs mutable-strings)
      '(rnrs r5rs)
      '(only (chezscheme) library import))
    #t))

It might also be useful to include debug in the set of identifiers imported from (chezscheme) to allow the debugger to be entered after an exception is raised.

Most of the identifiers bound in the default interaction environment that are not strictly compatible with the Revised\(^6\) Report are variables bound to procedures with extended interfaces, i.e., optional arguments or extended argument domains. The others are keywords bound to transformers that extend the Revised\(^6\) Report syntax in some way. This should not be a problem except for programs that count on exceptions being raised in cases that coincide with the extensions. For example, if a program passes the = procedure a single numeric argument and expects an exception to be raised, it will fail in the initial interaction environment because = returns #t when passed a single numeric argument.

Within the default interaction environment and those created as described above, variables

---

2.3. The Interaction Environment

---
that name built-in procedures are read-only, i.e., cannot be assigned, since they resolve to
the read-only bindings exported from the (chezscheme) library or some other library:

(set! cons +) ⇒ exception: cons is immutable

Before assigning a variable bound to the name of a built-in procedure, the programmer
must first define the variable. For example,

(define cons-count 0)
(define original-cons cons)
(define cons
  (lambda (x y)
    (set! cons-count (+ cons-count 1))
    (original-cons x y)))

redefines cons to count the number of times it is called, and

(set! cons original-cons)

assigns cons to its original value. Once a variable has been defined in the interaction
environment using define, a subsequent definition of the same variable is equivalent to a
set!, so

(define cons original-cons)

has the same effect as the set! above. The expression

(import (only (chezscheme) cons))

also binds cons to its original value. It also returns it to its original read-only state.
The simpler redefinition

(define cons (let () (import scheme) cons))

turns cons into a mutable variable with the same value as it originally had. Doing so,
however, prevents the compiler from generating efficient code for calls to cons or producing
warning messages when cons is passed the wrong number of arguments.

All identifiers not bound in the initial interaction environment and not defined by the
programmer are treated as “potentially bound” as variables to facilitate the definition of
mutually recursive procedures. For example, assuming that yin and yang have not been
defined,

(define yin (lambda () (- (yang) 1)))

defines yin at top level as a variable bound to a procedure that calls the value of the
top-level variable yang, even though yang has not yet been defined. If this is followed by

(define yang (lambda () (+ (yin) 1)))

the result is a mutually recursive pair of procedures that, when called, will loop indefinitely
or until the system runs out of space to hold the recursion stack. If \texttt{yang} must be defined as anything other than a variable, its definition should precede the definition of \texttt{yin}, since the compiler assumes \texttt{yang} is a variable in the absence of any indication to the contrary when \texttt{yang} has not yet been defined.

A subtle consequence of this useful quirk of the interaction environment is that the procedure \texttt{free-identifier=?} (Section 8.3 of \textit{The Scheme Programming Language, 4th Edition}) does not consider unbound library identifiers to be equivalent to (as yet) undefined top-level identifiers, even if they have the same name, because the latter are actually assumed to be valid variable bindings.

\begin{verbatim}
(libraries (A) (export a)
    (import (rnrs))
    (define-syntax a
        (lambda (x)
            (syntax-case x ()
                [(_ id) (free-identifier=? #'id #'undefined)])))
    (let () (import (A)) (a undefined)) ⇒ #f

If it is necessary that they have the same binding, as in the case where an identifier is used as an auxiliary keyword in a syntactic abstraction exported from a library and used at top level, the library should define and export a binding for the identifier.

(libraries (A) (export a aux-a)
    (import (rnrs) (only (chezscheme) syntax-error))
    (define-syntax aux-a
        (lambda (x)
            (syntax-error x "invalid context")))
    (define-syntax a
        (lambda (x)
            (syntax-case x (aux-a)
                [(_ aux-a) '#'okay]
                [(_ _) '#'oops]))))
    (let () (import (A)) (a aux-a)) ⇒ okay
    (let () (import (only (A) a)) (a aux-a)) ⇒ oops

This issue does not arise when libraries are used entirely within other libraries or within RNRS top-level programs, since the interaction environment does not come into play.

\end{verbatim}

\subsection*{2.4. Using Libraries and Top-Level Programs}

An R6RS library can be defined directly in the REPL, loaded explicitly from a file (using \texttt{load} or \texttt{load-library}), or loaded implicitly from a file via \texttt{import}. When defined directly in the REPL or loaded explicitly from a file, a library form can be used to redefine an existing library, but \texttt{import} never reloads a library once it has been defined.

A library to be loaded implicitly via \texttt{import} must reside in a file whose name reflects the name of the library. For example, if the library’s name is \texttt{(tools sorting)}, the base name of the file must be \texttt{sorting} with a valid extension, and the file must be in a directory
named tools which itself resides in one of the directories searched by import. The set of directories searched by import is determined by the library-directories parameter, and the set of extensions is determined by the library-extensions parameter.

The values of both parameters are lists of pairs of strings. The first string in each library-directories pair identifies a source-file base directory, and the second identifies the corresponding object-file base directory. Similarly, the first string in each library-extensions pair identifies a source-file extension, and the second identifies the corresponding object-file extension. The full path of a library source or object file consists of the source or object base followed by the components of the library name, separated by slashes, with the library extension added on the end. For example, for base /usr/lib/scheme, library name (app lib1), and extension .sls, the full path is /usr/lib/scheme/app/lib1.sls. So, if (library-directories) contains the pathnames "/usr/lib/scheme/libraries" and ".", and (library-extensions) contains the extensions .ss and .sls, the path of the (tools sorting) library must be one of the following.

/usr/lib/scheme/libraries/tools/sorting.ss
/usr/lib/scheme/libraries/tools/sorting.sls
./tools/sorting.ss
./tools/sorting.sls

When searching for a library, import first constructs a partial name from the list of components in the library name, e.g., /b for library (a b). It then searches for the partial name in each pair of base directories, in order, trying each of the source extensions then each of the object extensions in turn before moving onto the next pair of base directories. If the partial name is an absolute pathname, e.g., ~/.myappinit for a library named (~/.myappinit), only the specified absolute path is searched, first with each source extension, then with each object extension. If the expander finds both a source file and its corresponding object file, and the object file is not older than the source file, the expander loads the object file. If the object file does not exist, if the object file is older, or if after loading the object file, the expander determines it was built using a library or include file that has changed, the source file is loaded or compiled, depending on the value of the parameter compile-imported-libraries. If compile-imported-libraries is set to #t, the expander compiles the library via the value of the compile-library-handler parameter, which by default calls compile-library (which is described below). Otherwise, the expander loads the source file. (Loading the source file actually causes the code to be compiled, assuming the default value of current-eval, but the compiled code is not saved to an object file.)

The library-timestamp-mode parameter controls the meaning of “older” for comparing library sources and object files. An exception is raised during this process if a source or object file exists but is not readable or if an object file cannot be created.

The search process used by the expander when processing an import for a library that has not yet been loaded can be monitored by setting the parameter import-notify to #t. This parameter can be set from the command line via the --import-notify command-line option.

Whenever the expander determines it must compile a library to a file or load one from source, it adds the directory in which the file resides to the front of the source-directories
list while compiling or loading the library. This allows a library to include files stored in
or relative to its own directory.

When import compiles a library as described above, it does not also load the compiled
library, because this would cause portions of library to be reevaluated. Because of this,
run-time expressions in the file outside of a library form will not be evaluated. If such
expressions are present and should be evaluated, the library should be compiled ahead of
time or loaded explicitly.

A file containing a library may be compiled with compile-file or compile-library. The
only difference between the two is that the latter treats the source file as if it were prefixed
by an implicit #!r6rs, which disables Chez Scheme lexical extensions unless an explicit
#!chezscheme marker appears in the file. Any libraries upon which the library depends
must be compiled first. If one of the libraries imported by the library is subsequently
recompiled (say because it was modified), the importing library must also be recompiled.
Compilation and recompilation of imported libraries must be done explicitly by default but
is done automatically when the parameter compile-imported-libraries is set to #t before
compiling the importing library.

As with compile-file, compile-library can be used in “batch” mode via a shell command:

```
echo '(compile-library "filename")' | scheme -q
```

with single-quote marks surrounding the compile-library call omitted for Windows shells.

An RNRS top-level-program usually resides in a file, but one can also enter one directly
into the REPL using the top-level-program forms, e.g.:

```
(top-level-program
  (import (rnrs))
  (display "What’s up?\n"))
```

A top-level program stored in a file does not have the top-level-program wrapper, so the
same top-level program in a file is just:

```
(import (rnrs))
(display "What’s up?\n")
```

A top-level program stored in a file can be loaded from the file via the load-program
procedure. A top-level program can also be loaded via load, but not without affecting the
semantics. A program loaded via load is scoped at top level, where it can see all top-level
bindings, whereas a top-level program loaded via load-program is self-contained, i.e., it can
see only the bindings made visible by the leading import form. Also, the variable bindings
in a program loaded via load also become top-level bindings, whereas they are local to
the program when the program is loaded via load-program. Moreover, load-program, like
load-library, treats the source file as if it were prefixed by an implicit #!r6rs, which
disables Chez Scheme lexical extensions unless an explicit #!chezscheme marker appears
in the file. A program loaded via load is also likely to be less efficient. Since the program’s
variables are not local to the program, the compiler must assume they could change at any
time, which inhibits many of its optimizations.
Top-level programs may be compiled using `compile-program`, which is like `compile-file` but, as with `load-program`, properly implements the semantics and lexical restrictions of top-level programs. `compile-program` also copies the leading `#!` line, if any, from the source file to the object file, resulting in an executable object file. Any libraries upon which the top-level program depends, other than built-in libraries, must be compiled first. The program must be recompiled if any of the libraries upon which it depends are recompiled. Compilation and recompilation of imported libraries must be done explicitly by default but is done automatically when the parameter `compile-imported-libraries` is set to `#t` before compiling the importing library.

As with `compile-file` and `compile-library`, `compile-program` can be used in “batch” mode via a shell command:

```scheme
  echo '(compile-program "filename")' | scheme -q
```

with single-quote marks surrounding the `compile-program` call omitted for Windows shells. `compile-program` returns a list of libraries directly invoked by the compiled top-level program. When combined with the `library-requirements` and `library-object-filename` procedures, the list of libraries returned by `compile-program` can be used to determine the set of files that must be distributed with the compiled program file.

When run, a compiled program automatically loads the run-time code for each library upon which it depends, as if via `revisit`. If the program also imports one of the same libraries at run time, e.g., via the `environment` procedure, the system will attempt to load the compile-time information from the same file. The compile-time information can also be loaded explicitly from the same or a different file via `load` or `visit`.

### 2.5. Scheme Shell Scripts

When the `--script` command-line option is present, the named file is treated as a Scheme shell script, and the command-line is made available via the parameter `command-line`. This is primarily useful on Unix-based systems, where the script file itself may be made executable. To support executable shell scripts, the system ignores the first line of a loaded script if it begins with `#!` followed by a space or forward slash. For example, assuming that the Chez Scheme executable has been installed as `/usr/bin/scheme`, the following script prints its command-line arguments.

```scheme
  #!/usr/bin/scheme --script
  (for-each
    (lambda (x) (display x) (newline))
    (cdr (command-line)))
```

The following script implements the traditional Unix `echo` command.

```scheme
  #!/usr/bin/scheme --script
  (let ([args (cdr (command-line))])
    (unless (null? args)
      (let-values ([[newline? args]])
        (display (if newline? "\n" "") args)
      ))
  ```
Scripts may be compiled using `compile-script`, which is like `compile-file` but differs in that it copies the leading `#!` line from the source-file script into the object file.

If *Petite Chez Scheme* is installed, but not *Chez Scheme*, `/usr/bin/scheme` may be replaced with `/usr/bin/petite`.

The `--program` command-line option is like `--script` except that the script file is treated as an RNRS top-level program (Chapter 10). The following RNRS top-level program implements the traditional Unix `echo` command, as with the script above.

```scheme
#!/usr/bin/scheme --program
(import (rnrs))
(let ([args (cdr (command-line))])
  (unless (null? args)
    (let-values ([[newline? args]]
      (if (equal? (car args) "-n")
        (values #f (cdr args))
        (values #t args))]
      (do ([args args (cdr args)] [sep " " ""]) ((null? args))
        (display sep)
        (display (car args)))
      (when newline? (newline))))))
```

Again, if only *Petite Chez Scheme* is installed, `/usr/bin/scheme` may be replaced with `/usr/bin/petite`.

`scheme-script` may be used in place of `scheme --program` or `petite --program`, i.e.,

```scheme
#!/usr/bin/scheme-script
```

`scheme-script` runs *Chez Scheme*, if available, otherwise *Petite Chez Scheme*.

It is also possible to use `/usr/bin/env`, as recommended in the Revised\(^6\) Report nonnormative appendices, which allows `scheme-script` to appear anywhere in the user’s path.

```scheme
#!/usr/bin/env scheme-script
```

If a top-level program depends on libraries other than those built into *Chez Scheme*, the `--libdirs` option can be used to specify which source and object directories to search. Similarly, if a library upon which a top-level program depends has an extension other than one of the standard extensions, the `--libexts` option can be used to specify additional extensions to search.

These options set the corresponding *Chez Scheme* parameters `library-directories` and
library-extensions, which are described in Section 2.4. The format of the arguments to --libdirs and --libexts is the same: a sequence of substrings separated by a single separator character. The separator character is a colon (:), except under Windows where it is a semi-colon (;). Between single separators, the source and object strings, if both are specified, are separated by two separator characters. If a single separator character appears at the end of the string, the specified pairs are added to the front of the existing list; otherwise, the specified pairs replace the existing list.

For example, where the separator is a colon,

```
scheme --libdirs "/home/moi/lib:"
```

adds the source/object directory pair

`("/home/moi/lib" . "/home/moi/lib")`

to the front of the default set of library directories, and

```
scheme --libdirs "/home/moi/libsrc::/home/moi/libobj:"
```

adds the source/object directory pair

`("/home/moi/libsrc" . "/home/moi/libobj")`

to the front of the default set of library directories. The parameters are set after all boot files have been loaded.

If no --libdirs option appears and the CHEZSCHEMELIBDIRS environment variable is set, the string value of CHEZSCHEMELIBDIRS is treated as if it were specified by a --libdirs option. Similarly, if no --libexts option appears and the CHEZSCHEME-LIBEXTS environment variable is set, the string value of CHEZSCHEMELIBEXTS is treated as if it were specified by a --libexts option.

### 2.6. Optimization

To get the most out of the Chez Scheme compiler, it is necessary to give it a little bit of help. The most important assistance is to avoid the use of top-level (interaction-environment) bindings. Top-level bindings are convenient and appropriate during program development, since they simplify testing, redefinition, and tracing (Section 3.1) of individual procedures and syntactic forms. This convenience comes at a sizable price, however.

The compiler can propagate copies (of one variable to another or of a constant to a variable) and inline procedures bound to local, unassigned variables within a single top-level expression. For the procedures it does not inline, it can avoid constructing and passing unneeded closures, bypass argument-count checks, branch to the proper entry point in a case-lambda, and build rest arguments (more efficiently) on the caller side, where the length of the rest list is known at compile time. It can also discard the definitions of unreferenced variables, so there’s no penalty for including a large library of routines, only a few of which are actually used.
2.6. Optimization

It cannot do any of this with top-level variable bindings, since the top-level bindings can change at any time and new references to those bindings can be introduced at any time. Fortunately, it is easy to restructure a program to avoid top-level bindings. This is naturally accomplished for portable code by placing the code into a single RNRS top-level program or by placing a portion of the code in a top-level program and the remainder in one or more separate libraries. Although not portable, one can also put all of the code into a single top-level module form or let expression, perhaps using include to bring in portions of the code from separate files. The compiler performs some optimization even across library boundaries, so the penalty for breaking a program up in this manner is generally acceptable. The compiler also supports whole-program optimization (via compile-whole-program), which can be used to eliminate all overhead for placing portions of a program into separate libraries.

Once an application’s code has been placed into a single top-level program or into a top-level program and one or more libraries, the code can be loaded from source via load-program or compiled via compile-program and compile-library, as described in Section 2.4. Be sure not to use compile-file for the top-level program since this does not preserve the semantics nor result in code that is as efficient.

With an application structured as a single top-level program or as a top-level program and one or more libraries that do not interact frequently, we have done most of what can be done to help the compiler, but there are still a few more things we can do.

First, we can allow the compiler to generate “unsafe” code, i.e., allow the compiler to generate code in which the usual run-time type checks have been disabled. We do this by using the compiler’s “optimize level 3” when compiling the program and library files. This can be accomplished by setting the parameter optimize-level to 3 while compiling the library or program, e.g.:

\[
\text{(parameterize \{[optimize-level 3]\} (compile-program "filename"))}
\]

or in batch mode via the --optimize-level command-line option:

\[
\text{echo '}(\text{compile-program "filename"})' \mid \text{scheme -q --optimize-level 3}
\]

It may also be useful to experiment with some of the other compiler control parameters and also with the storage manager’s run-time operation. The compiler-control parameters, including optimize-level, are described in Section 12.6 and the storage manager control parameters are described in Section 13.1.

Finally, it is often useful to “profile” your code to determine that parts of the code that are executed most frequently. While this may help the system optimize your code, the primary benefit is to help you identify “hot spots” where you need to concentrate your own hand-optimization efforts. In these hot spots, consider using more efficient operators, like fixnum or flonum operators in place of generic arithmetic operators, and using explicit loops rather than nested combinations of linear list-processing operators like append, reverse, and map. These operators can make code more readable when used judiciously, but they can slow down time-critical code.
Section 12.7 describes how to use the compiler’s support for automatic profiling and profile-directed optimization. Be sure that profiling is not enabled when you compile your production code, since the code introduced into the generated code to perform the profiling adds significant run-time overhead.

### 2.7. Customization

*Chez Scheme* and *Petite Chez Scheme* are built from several subsystems: a “kernel” encapsulated in a static or shared library (dynamic link library) that contains operating-system interface and low-level storage management code, an executable that parses command-line arguments and calls into the kernel to initialize and run the system, a base boot file (`petite.boot`) that contains the bulk of the run-time library code, and an additional boot file (`scheme.boot`), for *Chez Scheme* only, that contains the compiler.

While the kernel and base boot file are essential to the operation of all programs, the executable may be replaced or even eliminated, and the compiler boot file need be loaded only if the compiler is actually used. In fact, the compiler is typically not loaded for distributed applications unless the application creates and executes code at run time.

The kernel exports a set of entry points that are used to initialize the Scheme system, load boot or heap files, run an interactive Scheme session, run script files, and deinitialize the system. In the threaded versions of the system, the kernel also exports entry points for activating, deactivating, and destroying threads. These entry points may be used to create your own executable image that has different (or no) command-line options or to run Scheme as a subordinate program within another program, i.e., for use as an extension language.

These entry points are described in Section 4.9 along with other entry points for accessing and modifying Scheme data structures and calling Scheme procedures.

The file `main.c` in the ’c’ subdirectory contains the “main” routine for the distributed executable image; look at this file to gain an understanding of how the system startup entry points are used.

### 2.8. Building and Distributing Applications

Although useful as a stand-alone Scheme system, *Petite Chez Scheme* was conceived as a run-time system for compiled *Chez Scheme* applications. The remainder of this section describes how to create and distribute such applications using *Petite Chez Scheme*. It begins with a discussion of the characteristics of *Petite Chez Scheme* and how it compares with *Chez Scheme*, then describes how to prepare application source code, how to build and run applications, and how to distribute them.

**Petite Chez Scheme Characteristics.** Although interpreter-based, *Petite Chez Scheme* evaluates Scheme source code faster than might be expected. Some of the reasons for this are listed below.
2.8. Building and Distributing Applications

- The run-time system is fully compiled, so library implementations of primitives ranging from + and car to sort and printf are just as efficient as in Chez Scheme, although they cannot be open-coded as in code compiled by Chez Scheme.

- The interpreter is itself a compiled Scheme application. Because it is written in Scheme, it directly benefits from various characteristics of Scheme that would have to be dealt with explicitly and with additional overhead in most other languages, including proper treatment of tail calls, first-class procedures, automatic storage management, and continuations.

- The interpreter employs a preprocessor that converts the code into a form that can be interpreted efficiently. In fact, the preprocessor shares its front end with the compiler, and this front end performs a variety of source-level optimizations.

Nevertheless, compiled code is still more efficient for most applications. The difference between the speed of interpreted and compiled code varies significantly from one application to another, but often amounts to a factor of five and sometimes to a factor of ten or more.

Several additional limitations result from the fact that Petite Chez Scheme does not include the compiler:

- The compiler must be present to process foreign-procedure and foreign-callable expressions, even when these forms are evaluated by the interpreter. These forms cannot be processed by the interpreter alone, so they cannot appear in source code to be processed by Petite Chez Scheme. Compiled versions of foreign-procedure and foreign-callable forms may, however, be included in compiled code loaded into Petite Chez Scheme.

- Inspector information is attached to code objects, which are generated only by the compiler, so source information and variable names are not available for interpreted procedures or continuations into interpreted procedures. This makes the inspector less effective for debugging interpreted code than it is for debugging compiled code.

- Procedure names are also attached to code objects, so while the compiler associates a name with each procedure when an appropriate name can be determined, the interpreter does not do so. This mostly impacts the quality of error messages, e.g., an error message might read “incorrect number of arguments to #<procedure>” rather than the likely more useful “incorrect number of arguments to #<procedure name>.”

- The compiler detects, at compile time, some potential errors that the interpreter does not detect and reports them via compile-time warnings that identify the expression or the location in the source file, if any, where the expression appears.

- Automatic profiling cannot be enabled for interpreted code as it is for compiled code when compile-profile is set to #t.

Except as noted above, Petite Chez Scheme does not restrict what programs can do, and like Chez Scheme, it places essentially no limits on the size of programs or the memory images they create, beyond the inherent limitations of the underlying hardware or operating system.

Compiled scripts and programs.
One simple mechanism for distributing an application is to structure it as a script or RNRS top-level program, use `compile-script` or `compile-program`, as appropriate to compile it as described in Section 2.5 and distribute the resulting object file along with a complete distribution of Petite Chez Scheme. When this mechanism is used on Unix-based systems, if the source file begins with `#!` and the path that follows is the path to the Chez Scheme executable, e.g., `/usr/bin/scheme`, the one at the front of the object file should be replaced with the path to the Petite Chez Scheme executable, e.g., `/usr/bin/petite`. The path may have to be adjusted by the application’s installation program based on where Petite Chez Scheme is installed on the target system. When used under Windows, the application’s installation program should set up an appropriate shortcut that starts Petite Chez Scheme with the --script or --program option, as appropriate, followed by the path to the object file.

The remainder of this section describes how to distribute applications that do not require Petite Chez Scheme to be installed as a stand-alone system on the target machine.

**Preparing Application Code.** While it is possible to distribute applications in source-code form, i.e., as a set of Scheme source files to be loaded into Petite Chez Scheme by the end user, distributing compiled code has two major advantages over distributing source code. First, compiled code is usually much more efficient, as discussed in the preceding section, and second, compiled code is in binary form and thus provides more protection for proprietary application code.

Application source code generally consists of a set of Scheme source files possibly augmented by foreign code developed specifically for the application and packaged in shared libraries (also known as shared objects or, on Windows, dynamic link libraries). The following assumes that any shared-library source code has been converted into object form; how to do this varies by platform. (Some hints are given in Section 4.7). The result is a set of one or more shared libraries that are loaded explicitly by the Scheme source code during program initialization.

Once the shared libraries have been created, the next step is to compile the Scheme source files into a set of Scheme object files. Doing so typically involves simply invoking `compile-file`, `compile-library`, or `compile-program`, as appropriate, on each source file to produce the corresponding object file. This may be done within a build script or “make” file via a command line such as the following:

```
echo '(compile-file "filename")' | scheme
```

which produces the object file `filename.so` from the source file `filename.ss`.

If the application code has been developed interactively or is usually loaded directly from source, it may be necessary to make some adjustments to a file to be compiled if the file contains expressions or definitions that affect the compilation of subsequent forms in the file. This can be accomplished via `eval-when` (Section 12.4). This is not typically necessary or desirable if the application consists of a set of RNRS libraries and programs.

You may also wish to disable generation of inspector information both to reduce the size of the compiled application code and to prevent others from having access to the expanded source code that is retained as part of the inspector information. To do so, set the parameter
generate-inspector-information to \#f while compiling each file. The downside of disabling inspector information is that the information will not be present if you need to debug your application, so it is usually desirable to disable inspector information only for production builds of your application. An alternative is to compile the code with inspector information enabled and strip out the debugging information later with strip-fasl-file.

The Scheme startup procedure determines what the system does when it is started. The default startup procedure loads the files listed on the command line (via load) and starts up a new café, like this:

\begin{verbatim}
(lambda fns (for-each load fns) (new-cafe))
\end{verbatim}

The startup procedure may be changed via the parameter scheme-start. The following example demonstrates the installation of a variant of the default startup procedure that prints the name of each file before loading it:

\begin{verbatim}
(scheme-start
 (lambda fns
   (for-each
     (lambda (fn)
       (printf "loading ~a ..." fn)
       (load fn)
       (printf "-%n")
     fn)
   fns)
   (new-cafe)))
\end{verbatim}

A typical application startup procedure would first invoke the application’s initialization procedure(s) and then start the application itself:

\begin{verbatim}
(scheme-start
 (lambda fns
   (initialize-application)
   (start-application fns)))
\end{verbatim}

Any shared libraries that must be present during the running of an application must be loaded during initialization. In addition, all foreign procedure expressions must be executed after the shared libraries are loaded so that the addresses of foreign routines are available to be recorded with the resulting foreign procedures. The following demonstrates one way in which initialization might be accomplished for an application that links to a foreign procedure show_state in the Windows shared library state.dll:

\begin{verbatim}
(define show-state)

(define app-init
  (lambda ()
    (load-shared-object "state.dll")
    (set! show-state
      (foreign-procedure "show_state" (integer-32) integer-32)))

(scheme-start
 (lambda fns
   (initialize-application)
   (start-application fns)))
\end{verbatim}
Building and Running the Application. Building and running an application is straightforward once all shared libraries have been built and Scheme source files have been compiled to object code.

Although not strictly necessary, we suggest that you concatenate your object files, if you have more than one, into a single object file via the `concatenate-object-files` procedure. Placing all of the object code into a single file simplifies both building and distribution of applications.

For top-level programs with separate libraries, `compile-whole-program` can be used to produce a single, fully optimized object file. Otherwise, when concatenating object files, put each library after the libraries it depends upon, with the program last.

With the Scheme object code contained within a single composite object file, it is possible to run the application simply by loading the composite object file into *Petite Chez Scheme*, e.g.:

```
petite app.so
```

where `app.so` is the name of the composite object file, and invoking the startup procedure to restart the system:

```
> ((scheme-start))
```

The point of setting `scheme-start`, however, is to allow the set of object files to be converted into a *boot file*. Boot files are loaded during the process of building the initial heap. Because of this, boot files have the following advantages over ordinary object files.

- Any code and data structures contained in the boot file or created while it is loaded is automatically compacted along with the base run-time library code and made static. Static code and data are never collected by the storage manager, so garbage collection overhead is reduced. (It is also possible to make code and data static explicitly at any time via the `collect` procedure.)

- The system looks for boot files automatically in a set of standard directories based on the name of the executable image, so you can install a copy of the *Petite Chez Scheme* executable image under your application’s name and spare your users from supplying any command-line arguments or running a separate script to load the application code.

When an application is packaged into a boot file, the source code that is compiled and converted into a boot file should set `scheme-start` to a procedure that starts the application, as shown in the example above. The application should not be started directly from the boot file, because boot files are loaded before final initialization of the Scheme system. The value of `scheme-start` is invoked automatically after final initialization.
A boot file is simply an object file containing the code for one or more source files, prefixed by a boot header. The boot header identifies a base boot file upon which the application directly depends, or possibly two or more alternatives upon which the application can be run. In most cases, petite.boot will be identified as the base boot file, but in a layered application it may be another boot file of your creation that in turn depends upon petite.boot. The base boot file, and its base boot file, if any, are loaded automatically when your application boot file is loaded.

Boot files are created with `make-boot-file`. This procedure accepts two or more arguments. The first is a string naming the file into which the boot header and object code should be placed, the second is a list of strings naming base boot files, and the remainder are strings naming input files. For example, the call:

```
(make-boot-file "app.boot" '("petite") "app1.so" "app2.ss" "app3.so")
```

creates the boot file app.boot that identifies a dependency upon petite.boot and contains the object code for app1.so, the object code resulting from compiling app2.ss, and the object code for app3.so. The call:

```
(make-boot-file "app.boot" '("scheme" "petite") "app.so")
```

creates a header file that identifies a dependency upon either scheme.boot or petite.boot, with the object code from app.so. In the former case, the system will automatically load petite.boot when the application boot file is loaded, and in the latter it will load scheme.boot if it can find it, otherwise petite.boot. This would allow your application to run on top of the full Chez Scheme if present, otherwise Petite Chez Scheme.

In most cases, you can construct your application so it does not depend upon features of scheme.boot (specifically, the compiler) by specifying only "petite" in the call to `make-boot-file`. If your application calls `eval`, however, and you wish to allow users to be able to take advantage of the faster execution speed of compiled code, then specifying both "scheme" and "petite" is appropriate.

Here is how we might create and run a simple “echo” application from a Linux shell:

```
echo '(suppress-greeting #t)' > myecho.ss
echo '(scheme-start (lambda fns (printf "-{~a~^ ~}

| scheme -b myecho.boot hello world
```

```
If we take the extra step of installing a copy of the Petite Chez Scheme executable as myecho and copying myecho.boot into the same directory as petite.boot (or set SCHEME-HEAPDIRS to include the directory containing myecho.boot), we can simply invoke `myecho` to run our echo application:

```
myecho hello world
```

**Distributing the Application.** Distributing an application can be as simple as creating
a distribution package that includes the following items:

- the *Petite Chez Scheme* distribution,
- the application boot file,
- any application-specific shared libraries,
- an application installation script.

The application installation script should install *Petite Chez Scheme* if not already installed on the target system. It should install the application boot file in the same directory as the *Petite Chez Scheme* boot file petite.boot is installed, and it should install the application shared libraries, if any, either in the same location or in a standard location for shared libraries on the target system. It should also create a link to or copy of the *Petite Chez Scheme* executable under the name of your application, i.e., the name given to your application boot file. Where appropriate, it should also install desktop and start-menu shortcuts to run the executable.

### 2.9. Command-Line Options

*Chez Scheme* recognizes the following command-line options.

- `--quiet` suppress greeting and prompt
- `--script path` run as shell script
- `--program path` run rnrs top-level program as shell script
- `--libdirs dir:` set library directories
- `--libexts ext:` set library extensions
- `--compile-imported-libraries` compile libraries before loading
- `--disable-library-timestamps` do not check modification dates on library sources
- `--import-notify` enable import search messages
- `--optimize-level 0 | 1 | 2 | 3` set initial optimize level
- `--debug-on-exception` on uncaught exception, call `debug`
- `--eedisable` disable expression editor
- `--eehistory off | path` expression-editor history file
- `--enable-object-counts` have collector maintain object counts
- `--retain-static-relocation` keep reloc info for compute-size, etc.
- `--boot path` load boot file
- `--Boot path` load boot file relative to the current directory
- `--verbose` trace boot-file search process
- `--version` print version and exit
- `--help` print help and exit
- `--pass through remaining args`

The following options are recognized but cause the system to print an error message and exit because saved heaps are no longer supported.

- `--heap path` load heap file
- `--saveheap[n] path` save heap file
- `--compact` toggle compaction flag
With the default scheme-start procedure (Section 2.8), any remaining command-line arguments are treated as the names of files to be loaded before Chez Scheme begins interacting with the user, unless the --script or --program is present, in which case the remaining arguments are made available to the script via the command-line parameter (Section 2.1).

Most of the options are described elsewhere in this chapter, and a few are self-explanatory. The remainder pertain to the loading of boot files at system start-up time and are described below.

When Chez Scheme is run, it looks for one or more boot files to load. Boot files contain the compiled Scheme code that implements most of the Scheme system, including the interpreter, compiler, and most libraries. Boot files may be specified explicitly on the command line via -b (relative to installation directory unless absolute or starting with a . or .. path element) or -B (relative to current directory unless absolute) options or implicitly. In the simplest case, no -b options are given and the necessary boot files are loaded automatically based on the name of the executable.

For example, if the executable name is “frob”, the system looks for “frob.boot” in a set of standard directories. It also looks for and loads any subordinate boot files required by “frob.boot”.

Subordinate boot files are also loaded automatically for the first boot file explicitly specified via the command line. Each boot file must be listed before those that depend upon it.

The --verbose option may be used to trace the file searching process and must appear before any boot arguments for which search tracing is desired.

Ordinarily, the search for boot files is limited to a set of installation directories, but this may be overridden by setting the environment variable SCHEMEHEAPDIRS. SCHEMEHEAPDIRS should be a colon-separated list of directories, listed in the order in which they should be searched. Within each directory, the two-character escape sequence “%/v” is replaced by the current version, and the two-character escape sequence “%/m” is replaced by the machine type. A percent followed by any other character is replaced by the second character; in particular, “/%x” is replaced by “%”, and “%:” is replaced by “;”. If SCHEMEHEAPDIRS ends in a non-escaped colon, the default directories are searched after those in SCHEMEHEAPDIRS; otherwise, only those listed in SCHEMEHEAPDIRS are searched.

Under Windows, semi-colons are used in place of colons, and one additional escape is recognized: “%x,” which is replaced by the directory in which the executable file resides. The default search path under Windows consists of “%x” and “%x\..\..\boot\%m.” The registry key HeapSearchPath in HKLM\SOFTWARE\Chez Scheme\csvversion, where version is the Chez Scheme version number, e.g., 7.9.4, can be set to override the default search path, and the SCHEMEHEAPDIRS environment variable overrides both the default and the registry setting, if any.

Boot files consist of ordinary compiled code and consist of a boot header and the compiled code for one or more source files. See Section 2.8 for instructions on how to create boot files.
3. Debugging

*Chez Scheme* has several features that support debugging. In addition to providing error messages when fully type-checked code is run, *Chez Scheme* also permits tracing of procedure calls, interruption of any computation, redefinition of exception and interrupt handlers, and inspection of any object, including the continuations of exceptions and interrupts.

Programmers new to Scheme or *Chez Scheme*, and even more experienced Scheme programmers, might want to consult the tutorial “How to Debug Chez Scheme Programs.” HTML and PDF versions are available at [http://www.cs.indiana.edu/chezscheme/debug/](http://www.cs.indiana.edu/chezscheme/debug/)

3.1. Tracing

Tracing is one of the most useful mechanisms for debugging Scheme programs. *Chez Scheme* permits any primitive or user-defined procedure to be traced. The trace package prints the arguments and return values for each traced procedure with a compact indentation mechanism that shows the nesting depth of calls. The distinction between tail calls and nontail calls is reflected properly by an increase in indentation for nontail calls only. For nesting depths of 10 or greater, a number in brackets is used in place of indentation to signify nesting depth.

This section covers the mechanisms for tracing procedures and controlling trace output.

```
(trace-lambda name formals body1 body2 ...)  ; syntax
returns: a traced procedure
libraries: (chezscheme)
```

A `trace-lambda` expression is equivalent to a `lambda` expression with the same formals and body except that trace information is printed to the trace output port whenever the procedure is invoked, using `name` to identify the procedure. The trace information shows the value of the arguments passed to the procedure and the values returned by the procedure, with indentation to show the nesting of calls.

The traced procedure `half` defined below returns the integer quotient of its argument and 2.
(define half
  (trace-lambda half (x)
    (cond
      [(zero? x) 0]
      [(odd? x) (half (- x 1))]
      [(even? x) (+ (half (- x 1)) 1)])])

A trace of the call (half 5), which returns 2, is shown below.

| (half 5) |
| (half 4) |
| (half 3) |
| (half 2) |
| (half 1) |
| (half 0) |
| 0 |
| 1 |
| 2 |

This example highlights the proper treatment of tail and nontail calls by the trace package. Since half tail calls itself when its argument is odd, the call (half 4) appears at the same level of indentation as the call (half 5). Furthermore, since the return values of (half 5) and (half 4) are necessarily the same, only one return value is shown for both calls.

(trace-case-lambda name clause ...) syntax
returns: a traced procedure
libraries: (chezscheme)

A trace-case-lambda expression is equivalent to a case-lambda expression with the same clauses except that trace information is printed to the trace output port whenever the procedure is invoked, using name to identify the procedure. The trace information shows the value of the arguments passed to the procedure and the values returned by the procedure, with indentation to show the nesting of calls.

(trace-let name ((var expr) ...) body1 body2 ...) syntax
returns: the values of the body body1 body2 ...
libraries: (chezscheme)

A trace-let expression is equivalent to a named let expression with the same name, bindings, and body except that trace information is printed to the trace output port on entry or reentry (via invocation of the procedure bound to name) into the trace-let expression.

A trace-let expression of the form

(trace-let name ([var expr] ...) body1 body2 ...)

can be rewritten in terms of trace-lambda as follows:
3.1. Tracing

```scheme
((letrec ([name
  (trace-lambda name (var ...)
    body1 body2 ...)])
  name)
 expr ...)
```

trace-let may be used to trace ordinary let expressions as well as let expressions as long as the name inserted along with the trace-let keyword in place of let does not appear free within the body of the let expression. It is also sometimes useful to insert a trace-let expression into a program simply to display the value of an arbitrary expression at the current trace indentation. For example, a call to the following variant of half

```scheme
(define half
  (trace-lambda half (x)
    (cond
      [(zero? x) 0]
      [(odd? x) (half (trace-let decr-value () (- x 1)))]
      [(even? x) (+ (half (- x 1)) 1)])))
```

with argument 5 results in the trace:

```
|(half 5)
 | (decr-value)
 | 4
 |(half 4)
 | (half 3)
 | |(decr-value)
 | | 2
 |(half 2)
 | |(half 1)
 | | |(decr-value)
 | | | 0
 | |(half 0)
 | 1
 |2
```

**trace-do** `((var init update) ...) (test result ...) expr ...)` syntax

returns: the values of the last result expression

libraries: (chezscheme)

A trace-do expression is equivalent to a do expression with the same subforms, except that trace information is printed to the trace output port, showing the values of var ... and each iteration and the final value of the loop on termination. For example, the expression

```scheme
(trace-do ([old '(a b c) (cdr old)]
  [new '()] (cons (car old) new)])
((null? old) new))
```

produces the trace
and returns \((c \ b \ a)\).

\[
\text{(trace } \text{var}_1 \text{ var}_2 \ldots )
\]

\text{syntax}

\text{returns: a list of } \text{var}_1 \text{ var}_2 \ldots

\[
\text{(trace)}
\]

\text{syntax}

\text{returns: a list of all currently traced top-level variables}

\text{libraries: (chezscheme)}

In the first form, \text{trace} reassigns the top-level values of \text{var}_1 \ \text{var}_2 \ldots, whose values must be procedures, to equivalent procedures that display trace information in the manner of \text{trace-lambda}.

\text{trace} works by encapsulating the old value of each \text{var} in a traced procedure. It could be defined approximately as follows. (The actual version records and returns information about traced variables.)

\[
\text{(define-syntax trace}
\]

\text{(syntax-rules ()}

\[
\text{[(_ var \ldots )}
\]

\text{(begin}

\[
\text{(set-top-level-value! 'var}
\]

\text{(let ([p (top-level-value 'var)])}

\text{(trace-lambda var args (apply p args))})

\ldots ])

\text{]])}

Tracing for a procedure traced in this manner may be disabled via \text{untrace} (see below), an assignment of the corresponding variable to a different, untraced value, or a subsequent use of \text{trace} for the same variable. Because the value is traced and not the binding, however, a traced value obtained before tracing is disabled and retained after tracing is disabled will remain traced.

\text{trace} without subexpressions evaluates to a list of all currently traced variables. A variable is currently traced if it has been traced and not subsequently untraced or assigned to a different value.

The following transcript demonstrates the use of \text{trace} in an interactive session.

\[
> \text{(define half}
\]

\text{(lambda (x)}

\text{(cond}

\[
\text{[(zero? x) 0]}
\]

\[
\text{[(odd? x) (half (- x 1))]}
\]

\[
\text{[(even? x) (+ (half (- x 1)) 1)])}}
\]

\[
> \text{(half 5)}
\]

2
3.1. Tracing

> (trace half)
(half)
> (half 5)
| (half 5)
| (half 4)
| (half 3)
| (half 2)
| | (half 1)
| | (half 0)
| | 0
| 1
|2
2
> (define traced-half half)
> (untrace half)
(half)
> (half 2)
1
> (traced-half 2)
| (half 2)
| 1
|1
1

(untrace var1 var2 ...)
syntax
(untrace)
syntax

returns: a list of untraced variables

libraries: (chezscheme)

untrace restores the original (pre-trace) top-level values of each currently traced variable in \texttt{var1 var2 ...}, effectively disabling the tracing of the values of these variables. Any variable in \texttt{var1 var2 ...} that is not currently traced is ignored. If \texttt{untrace} is called without arguments, the values of all currently traced variables are restored.

The following transcript demonstrates the use of \texttt{trace} and \texttt{untrace} in an interactive session to debug an incorrect procedure definition.

> (define square-minus-one
  (lambda (x)
    (- (* x x) 2)))
> (square-minus-one 3)
7
> (trace square-minus-one * -)
(square-minus-one * -)
> (square-minus-one 3)
|(square-minus-one 3)
| (* 3 3)
| 9
|(- 9 2)
|7
The first call to `square-minus-one` indicates there is an error, the second (traced) call indicates the step at which the error occurs, the third call demonstrates that the fix works, and the fourth call demonstrates that `untrace` does not wipe out the fix.

`trace-output-port` thread parameter

`trace-output-port` is a parameter that determines the output port to which tracing information is sent. When called with no arguments, `trace-output-port` returns the current trace output port. When called with one argument, which must be a textual output port, `trace-output-port` changes the value of the current trace output port.

`trace-print` thread parameter

The value of `trace-print` must be a procedure of two arguments, an object and an output port. The trace package uses the value of `trace-print` to print the arguments and return values for each call to a traced procedure. `trace-print` is set to `pretty-print` by default. The trace package sets `pretty-initial-indent` to an appropriate value for the current nesting level before calling the value of `trace-print` so that multiline output can be indented properly.

`trace-define` syntax

`trace-define` is a convenient shorthand for defining variables bound to traced procedures.
of the same name. The first form is equivalent to

```
(define var
  (let ([x expr])
    (trace-lambda var args
      (apply x args))))
```

and the second is equivalent to

```
(define var
  (trace-lambda var idspec
    body1 body2 ...))
```

In the former case, `expr` must evaluate to a procedure.

> (let ()
   (trace-define plus
     (lambda (x y)
       (+ x y))
     (list (plus 3 4) (+ 5 6)))
| (plus 3 4)
| 7
| (7 11)

```
(trace-define-syntex keyword expr) syntax
returns: unspecified
libraries: (chezscheme)
```

`trace-define-syntex` traces the input and output to the transformer value of `expr`, stripped of the contextual information used by the expander to maintain lexical scoping.

> (trace-define-syntex let*)
  (syntax-rules ()
    [[(x e) m ...] b1 b2 ...]
    (let ((x e))
      (let* (m ...) b1 b2 ...))
    (let* (m ... b1 b2 ...)))

> (let* ([x 3] [y (+ x x)] (list x y))
| (let* (let* [(x 3) (y (+ x x))] (list x y))
| (let* ([y (+ x x)] (list x y)))
| (let* ([y (+ x x)] (list x y))
| (let ([y (+ x x)]) (let* () (list x y)))
| (let* (let* () (list x y)))
| (let () (list x y))
| (3 6)

Without contextual information, the displayed forms are more readable but less precise, since different identifiers with the same name are indistinguishable, as shown in the example below.
> (let ([x 0])
  (trace-define-syntax a
   (syntax-rules ()
     [(_ y) (eq? x y)]))
 (let ([x 1])
   (a x)))
| (a (a x))
| (eq? x x)
#f

3.2. The Interactive Debugger

The interactive debugger is entered as a result of a call to the procedure `debug` after an exception is handled by the default exception handler. It can also be entered directly from the default exception handler, for serious or non-warning conditions, if the parameter `debug-on-exception` is true.

Within the debugger, the command “?” lists the debugger command options. These include commands to:

- inspect the raise continuation,
- display the condition,
- inspect the condition, and
- exit the debugger.

The raise continuation is the continuation encapsulated within the condition, if any. The standard exception reporting procedures and forms `assert`, `assertion-violation`, and `error` as well as the Chez Scheme procedures `assertion-violationf`, `errorf`, and `syntax-error` all raise exceptions with conditions that encapsulate the continuations of their calls, allowing the programmer to inspect the frames of pending calls at the point of a violation, error, or failed assertion.

A variant of the interactive debugger, the break handler, is entered as the result of a keyboard interrupt handled by the default keyboard-interrupt handler or an explicit call to the procedure `break` handled by the default break handler. Again, the command “?” lists the command options. These include commands to:

- exit the break handler and continue,
- reset to the current café,
- abort the entire Scheme session,
- enter a new café,
- inspect the current continuation, and
- display program statistics (run time and memory usage).

It is also usually possible to exit from the debugger or break handler by typing the end-of-file character (“control-D” under Unix, “control-Z” under Windows).
3.3. The Interactive Inspector

When the default exception handler receives a serious or non-warning condition, it displays the condition and resets to the current café. Before it resets, it saves the condition in the parameter `debug-condition`. The `debug` procedure may be used to inspect the condition. Whenever one of the built-in error-reporting mechanisms is used to raise an exception, the continuation at the point where the exception was raised can be inspected as well. More generally, `debug` allows the continuation contained within any continuation condition created by `make-continuation-condition` to be inspected.

If the parameter `debug-on-exception` is set to `#t`, the default exception handler enters the debugger directly for all serious and non-warning conditions, delaying its reset until after the debugger exits. The `--debug-on-exception` command-line option may be used to set `debug-on-exception` to `#t` from the command line, which is particularly useful when debugging scripts or top-level programs run via the `--script` or `--program` command-line options.

3.3. The Interactive Inspector

The inspector may be called directly via the procedure `inspect` or indirectly from the debugger. It allows the programmer to examine circular objects, objects such as ports and procedures that do not have a reader syntax, and objects such as continuations and variables that are not directly accessible by the programmer, as well as ordinary printable Scheme objects.

The primary intent of the inspector is examination, not alteration, of objects. The values of assignable variables may be changed from within the inspector, however. Assignable variables are generally limited to those for which assignments occur in the source program. It is also possible to invoke arbitrary procedures (including mutation procedures such as `set-car!`) on an object. No mechanism is provided for altering objects that are inherently immutable, e.g., nonassignable variables, procedures, and bignums, since doing so can violate assumptions made by the compiler and run-time system.

The user is presented with a prompt line that includes a printed representation of the current object, abbreviated if necessary to fit on the line. Various commands are provided for displaying objects and moving around inside of objects. On-line descriptions of the command options are provided. The command “?” displays commands that apply specifically to the current object. The command “??” displays commands that are always applicable. The command “h” provides a brief description of how to use the inspector. The end-of-file character or the command “q” exits the inspector.
(inspect obj)  
procedure

returns: unspecified
libraries: (chezscheme)

Invokes the inspector on obj, as described above. The commands recognized by the inspector are listed below, categorized by the type of the current object.

Generally applicable commands

help or h displays a brief description of how to use the inspector.

? displays commands applicable to the current type of object.

?? displays the generally applicable commands.

print or p prints the current object (using pretty-print).

write or w writes the current object (using write).

size writes the size in bytes occupied by the current object (determined via compute-size), including any objects accessible from the current object except those for which the size was previously requested during the same interactive inspector session.

find expr [ g ] evaluates expr, which should evaluate to a procedure of one argument, and searches (via make-object-finder) for the first occurrence of an object within the current object for which the predicate returns a true value, treating immediate values (e.g., fixnums), values in generations older than g, and values already visited during the search as leaves. If g is not unspecified, it defaults to the current maximum generation, i.e., the value of collect-maximum-generation. If specified, g must be an exact nonnegative integer less than or equal to the current maximum generation or the symbol static representing the static generation. If such an object is found, the inspector’s focus moves to that object as if through a series of steps that lead from the current object to the located object, so that the up command can be used to determine where the object was found relative to the original object.

find-next repeats the last find, locating an occurrence not previously found, if any.

up or u n returns to the nth previous level. Used to move outwards in the structure of the inspected object. n defaults to 1.

top or t returns to the outermost level of the inspected object.

forward or f moves to the nth next expression. Used to move from one element to another of an object containing a sequence of elements, such as a list, vector, record, frame, or closure. n defaults to 1.

back or b moves to the nth previous expression. Used to move from one element to another of an object containing a sequence of elements, such as a list, vector, record, frame, or closure. n defaults to 1.
3.3. The Interactive Inspector

=> expr sends the current object to the procedure value of expr. expr may begin on the current or following line and may span multiple lines.

file path opens the source file at the specified path for listing. The parameter source-directories (Section 12.5) determines the set of directories searched for source files.

list line count lists count lines of the current source file (see file) starting at line. line defaults to the end of the previous set of lines listed and count defaults to ten or the number of lines previously listed. If line is negative, listing begins line lines before the previous set of lines listed.

files shows the currently open source files.

mark or m m marks the current location with the symbolic mark m. If m is not specified, the current location is marked with a unique default mark.

goto or g m returns to the location marked m. If m is not specified, the inspector returns to the location marked with the default mark.

new-cafe or n enters a new read-eval-print loop (café), giving access to the normal top-level environment.

quit or q exits from the inspector.

reset or r resets to the current café.

abort or a x aborts from Scheme with exit status x, which defaults to -1.

Continuation commands

show-frames or sf shows the next n frames. If n is not specified, all frames are displayed.

depth displays the number of frames in the continuation.

down or d n move to the nth frame down in the continuation. n defaults to 1.

show or s shows the continuation (next frame) and, if available, the calling procedure source, the pending call source, the closure, and the frame and free-variable values. Source is available only if generation of inspector information was enabled during compilation of the corresponding lambda expression.

show-local or sl is like show or s except that free variable values are not shown. (If present, free variable values can be found by inspecting the closure.)

length or l displays the number of elements in the topmost frame of the continuation.
ref or r moves to the \textit{nth} or named frame element. \textit{n} defaults to 0. If multiple elements have the same name, only one is accessible by name, and the others must be accessed by number.

code or c moves to the source for the calling procedure.

call moves to the source for the pending call.

file opens the source file containing the pending call, if known. The parameter \texttt{source-directories} (Section \ref{source-directories}) determines the list of source directories searched for source files identified by relative path names.

For absolute pathnames starting with a / (or \ or a directory specifier under Windows), the inspector tries the absolute pathname first, then looks for the last (filename) component of the path in the list of source directories. For pathnames starting with ./ (or .\ under Windows) or ../ (or ..\ under Windows), the inspector looks in "." or ".." first, as appropriate, then for the entire .- or ..-prefixed pathname in the source directories, then for the last (filename) component in the source directories. For other (relative) pathnames, the inspector looks for the entire relative pathname in the list of source directories, then the last (filename) component in the list of source directories.

If a file by the same name as but different contents from the original source file is found during this process, it will be skipped over. This typically happens because the file has been modified since it was compiled. Pass an explicit filename argument to force opening of a particular file (see the generally applicable commands above).

eval or e \texttt{expr} evaluates the expression \texttt{expr} in an environment containing bindings for the elements of the frame. Within the evaluated expression, the value of each frame element \textit{n} is accessible via the variable \%\textit{n}. Named elements are accessible via their names as well. Names are available only if generation of inspector information was enabled during compilation of the corresponding lambda expression.

set! or ! \texttt{n e} sets the value of the \textit{nth} frame element to \texttt{e}, if the frame element corresponds to an assignable variable. \textit{n} defaults to 0.

\textbf{Procedure commands}

show or s shows the source and free variables of the procedure. Source is available only if generation of inspector information was enabled during compilation of the corresponding lambda expression.

code or c moves to the source for the procedure.

file opens the file containing the procedure’s source code, if known. See the description of the continuation file entry above for more information.

length or l displays the number of free variables whose values are recorded in the procedure object.
3.3. The Interactive Inspector

ref or r moves to the nth or named free variable. n defaults to 0. If multiple free variables have the same name, only one is accessible by name, and the others must be accessed by number.

set! or ! n e sets the value of the nth free variable to e, if the variable is assignable. n defaults to 0.

eval or e expr evaluates the expression expr in an environment containing bindings for the free variables of the procedure. Within the evaluated expression, the value of each free variable n is accessible via the variable \%n. Named free variables are accessible via their names as well. Names are available only if generation of inspector information was enabled during compilation of the corresponding lambda expression.

Pair (list) commands

show or s n shows the first n elements of the list. If n is not specified, all elements are displayed.

length or l displays the list length.

car moves to the object in the car of the current object.

cdr moves to the object in the cdr.

ref or r n moves to the nth element of the list. n defaults to 0.

tail n moves to the nth cdr of the list. n defaults to 1.

Vector, Bytevector, and Fxvector commands

show or s n shows the first n elements of the vector. If n is not specified, all elements are displayed.

length or l displays the vector length.

ref or r n moves to the nth element of the vector. n defaults to 0.

String commands

show or s n shows the first n elements of the string. If n is not specified, all elements are displayed.

length or l displays the string length.

ref or r n moves to the nth element of the string. n defaults to 0.

unicode n displays the first n elements of the string as hexadecimal Unicode scalar values.
ascii $n$ displays the first $n$ elements of the string as hexadecimal ASCII values, using -- to denote characters whose Unicode scalar values are not in the ASCII range.

**Symbol commands**

*show* or *s* shows the fields of the symbol.

*value* or *v* moves to the top-level value of the symbol.

*name* or *n* moves to the name of the symbol.

*property-list* or *pl* moves to the property list of the symbol.

*ref* or *r* $n$ moves to the $n$th field of the symbol. Field 0 is the top-level value of the symbol, field 1 is the symbol’s name, and field 2 is its property list. $n$ defaults to 0.

**Character commands**

*unicode* displays the hexadecimal Unicode scalar value for the character.

*ascii* displays the hexadecimal ASCII code for the character, using -- to denote characters whose Unicode scalar values are not in the ASCII range.

**Box commands**

*show* or *s* shows the contents of the box.

*unbox* or *ref* or *r* moves to the boxed object.

**Port commands**

*show* or *s* shows the fields of the port, including the input and output size, index, and buffer fields.

*name* moves to the port’s name.

*handler* moves to the port’s handler.

*output-buffer* or *ob* moves to the port’s output buffer.

*input-buffer* or *ib* moves to the port’s input buffer.

**Record commands**

*show* or *s* shows the contents of the record.
fields moves to the list of field names of the record.

name moves to the name of the record.

rtd moves to the record-type descriptor of the record.

ref or r name moves to the named field of the record, if accessible.

set! or ! name value sets the value of the named field of the record, if mutable.

Transport Link Cell (TLC) commands

show or s shows the fields of the TLC.

keyval moves to the keyval of the TLC.

tconc moves to the tconc of the TLC.

next moves to the next link of the TLC.

ref or r n moves to the nth field of the symbol. Field 0 is the keyval, field 1 the tconc, and field 2 the next link. n defaults to 0.

3.4. The Object Inspector

A facility for noninteractive inspection is also provided to allow construction of different inspection interfaces. Like the interactive facility, it allows objects to be examined in ways not ordinarily possible. The noninteractive system follows a simple, object-oriented protocol. Ordinary Scheme objects are encapsulated in procedures, or inspector objects, that take symbolic messages and return either information about the encapsulated object or new inspector objects that encapsulate pieces of the object.

(inspect/object object) procedure

returns: an inspector object procedure

libraries: (chezscheme)

inspect/object is used to turn an ordinary Scheme object into an inspector object. All inspector objects accept the messages type, print, write, and size. The type message returns a symbolic representation of the type of the object. The print and write messages must be accompanied by a port parameter. They cause a representation of the object to be written to the port, using the Scheme procedures pretty-print and write. The size message returns a fixnum representing the size in bytes occupied by the object, including any objects accessible from the current object except those for which the size was already requested via an inspector object derived from the argument of the same inspect/object call.

All inspector objects except for variable inspector objects accept the message value, which returns the actual object encapsulated in the inspector object.
(define x (inspect/object '(1 2 3)))
(x 'type) ⇒ pair
(define p (open-output-string))
(x 'write p)
(get-output-string p) ⇒ "(1 2 3)"
(x 'length) ⇒ (proper 3)
(define y (x 'car))
(y 'type) ⇒ simple
(y 'value) ⇒ 1

**Pair inspector objects.** Pair inspector objects contain Scheme pairs.

*(pair-object 'type)* returns the symbol *pair*.

*(pair-object 'car)* returns an inspector object containing the “car” field of the pair.

*(pair-object 'cdr)* returns an inspector object containing the “cdr” field of the pair.

*(pair-object 'length)* returns a list of the form *(type count)*. The type field contains the symbol *proper*, the symbol *improper*, or the symbol *circular*, depending on the structure of the list. The count field contains the number of distinct pairs in the list.

**Box inspector objects.** Box inspector objects contain *Chez Scheme* boxes.

*(box-object 'type)* returns the symbol *box*.

*(box-object 'unbox)* returns an inspector object containing the contents of the box.

**TLC inspector objects.** Box inspector objects contain *Chez Scheme* boxes.

*(tlc-object 'type)* returns the symbol *tlc*.

*(tlc-object 'keyval)* returns an inspector object containing the TLC’s keyval.

*(tlc-object 'tconc)* returns an inspector object containing the TLC’s tconc.

*(tlc-object 'next)* returns an inspector object containing the TLC’s next link.

**Vector, String, Bytevector, and Fxvector inspector objects.** Vector (bytevector, string, fxvector) inspector objects contain Scheme vectors (bytevectors, strings, fxvectors).

*(vector-object 'type)* returns the symbol *vector (string, bytevector, fxvector)*.

*(vector-object 'length)* returns the number of elements in the vector or string.

*(vector-object 'ref n)* returns an inspector object containing the *nth* element of the vector or string.
3.4. The Object Inspector

Simple inspector objects. Simple inspector objects contain unstructured, unmodifiable objects. These include numbers, booleans, the empty list, the end-of-file object, and the void object. They may be examined directly by asking for the value of the object.

(simple-object 'type) returns the symbol simple.

Unbound inspector objects. Although unbound objects are not normally accessible to Scheme programs, they may be encountered when inspecting variables.

(unbound-object 'type) returns the symbol unbound.

Procedure inspector objects. Procedure inspector objects contain Scheme procedures.

(procedure-object 'type) returns the symbol procedure.

(procedure-object 'length) returns the number of free variables.

(procedure-object 'ref n) returns an inspector object containing the nth free variable of the procedure. See the description below of variable inspector objects. n must be nonnegative and less than the length of the procedure.

(procedure-object 'eval expr) evaluates expr and returns its value. The values of the procedure’s free variables are bound within the evaluated expression to identifiers of the form %n, where n is the location number displayed by the inspector. The values of named variables are also bound to their names.

(procedure-object 'code) returns an inspector object containing the procedure’s code object. See the description below of code inspector objects.

Continuation inspector objects. Continuations created by call/cc are actually procedures. However, when inspecting such a procedure the underlying data structure that embodies the continuation may be exposed. A continuation structure contains the location at which computation is to resume, the variable values necessary to perform the computation, and a link to the next continuation.

(continuation-object 'type) returns the symbol continuation.

(continuation-object 'length) returns the number of free variables.

(continuation-object 'ref n) returns an inspector object containing the nth free variable of the continuation. See the description below of variable inspector objects. n must be nonnegative and less than the length of the continuation.

(continuation-object 'eval expr) evaluates expr and returns its value. The values of frame locations are bound within the evaluated expression to identifiers of the form %n, where n is the location number displayed by the inspector. The values of named locations are also bound to their names.
(continuation-object 'code) returns an inspector object containing the code object for the procedure that was active when the current continuation frame was created. See the description below of code inspector objects.

(continuation-object 'depth) returns the number of frames in the continuation.

(continuation-object 'link) returns an inspector object containing the next continuation frame. The depth must be greater than 1.

(continuation-object 'link* n) returns an inspector object containing the nth continuation link. n must be less than the depth.

(continuation-object 'source) returns an inspector object containing the source information attached to the continuation (representing the source for the application that resulted in the formation of the continuation) or #f if no source information is attached.

(continuation-object 'source-object) returns an inspector object containing the source object for the procedure application that resulted in the formation of the continuation or #f if no source object is attached.

(continuation-object 'source-path) attempts to find the pathname of the file containing the source for the procedure application that resulted in the formation of the continuation. If successful, three values are returned to identify the file and position of the application within the file: path, line, and char. Two values, a file name and an absolute character position, are returned if the file name is known but the named file cannot be found. The search may be unsuccessful even if a file by the expected name is found in the path if the file has been modified since the source code was compiled. If no file name is known, no values are returned. The parameter source-directories (Section 12.5) determines the set of directories searched for source files identified by relative path names.

Code inspector objects. Code inspector objects contain Chez Scheme code objects.

(code-object 'type) returns the symbol code.

(code-object 'name) returns a string or #f. The name associated with a code inspector object is the name of the variable to which the procedure was originally bound or assigned. Since the binding of a variable can be changed, this name association may not always be accurate. #f is returned if the inspector cannot determine a name for the procedure.

(code-object 'realm) returns a symbol or #f. The realm of a code object is determined by the compile-procedure-realm parameter at the time that the code object is compiled.

(code-object 'source) returns an inspector object containing the source information attached to the code object or #f if no source information is attached.

(continuation-object 'source-object) returns an inspector object containing the source object for the code object or #f if no source object is attached.
3.4. The Object Inspector

(code-object 'source-path) attempts to find the pathname of the file containing the source for the lambda expression that produced the code object. If successful, three values are returned to identify the file and position of the application within the file: path, line, and char. Two values, a file name and an absolute character position, are returned if the file name is known but the named file cannot be found. The search may be unsuccessful even if a file by the expected name is found in the path if the file has been modified since the source code was compiled. If no file name is known, no values are returned. The parameter source-directories (Section 12.5) determines the set of directories searched for source files identified by relative path names.

(code-object 'free-count) returns the number of free variables in any procedure for which this is the corresponding code.

Variable inspector objects. Variable inspector objects encapsulate variable bindings. Although the actual underlying representation varies, the variable inspector object provides a uniform interface.

(variable-object 'type) returns the symbol variable.

(variable-object 'name) returns a symbol or #f. #f is returned if the name is not available or if the variable is a compiler-generated temporary variable. Variable names are not retained when the parameter generate-inspector-information (page 12.6) is false during compilation.

(variable-object 'ref) returns an inspector object containing the current value of the variable.

(variable-object 'set! e) returns unspecified, after setting the current value of the variable to e. An exception is raised with condition type &assertion if the variable is not assignable.

Port inspector objects. Port inspector objects contain ports.

(port-object 'type) returns the symbol port.

(port-object 'input?) returns #t if the port is an input port, #f otherwise.

(port-object 'output?) returns #t if the port is an output port, #f otherwise.

(port-object 'binary?) returns #t if the port is a binary port, #f otherwise.

(port-object 'closed?) returns #t if the port is closed, #f if the port is open.

(port-object 'name) returns an inspector object containing the port’s name.

(port-object 'handler) returns a procedure inspector object encapsulating the port handler, such as would be returned by port-handler.

(port-object 'output-size) returns the output buffer size as a fixnum if the port is an output port (otherwise the value is unspecified).
(port-object 'output-index) returns the output buffer index as a fixnum if the port is an output port (otherwise the value is unspecified).

(port-object 'output-buffer) returns an inspector object containing the string used for buffered output.

(port-object 'input-size) returns the input buffer size as a fixnum if the port is an input port (otherwise the value is unspecified).

(port-object 'input-index) returns the input buffer index as a fixnum if the port is an input port (otherwise the value is unspecified).

(port-object 'input-buffer) returns an inspector object containing the string used for buffered input.

Symbol inspector objects. Symbol inspector objects contain symbols. These include gensyms.

(symbol-object 'type) returns the symbol symbol.

(symbol-object 'name) returns a string inspector object. The string name associated with a symbol inspector object is the print representation of a symbol, such as would be returned by the procedure symbol->string.

(symbol-object 'gensym?) returns #t if the symbol is a gensym, #f otherwise. Gensyms are created by gensym.

(symbol-object 'top-level-value) returns an inspector object containing the global value of the symbol.

(symbol-object 'property-list) returns an inspector object containing the property list for the symbol.

Record inspector objects. Record inspector objects contain records.

(record-object 'type) returns the symbol record.

(record-object 'name) returns a string inspector object corresponding to the name of the record type.

(record-object 'fields) returns an inspector object containing a list of the field names of the record type.

(record-object 'length) returns the number of fields.

(record-object 'rtd) returns an inspector object containing the record-type descriptor of the record type.
3.5. Locating objects

(record-object 'accessible? name) returns #t if the named field is accessible, #f otherwise. A field may be inaccessible if optimized away by the compiler.

(record-object 'ref name) returns an inspector object containing the value of the named field. An exception is raised with condition type &assertion if the named field is not accessible.

(record-object 'mutable? name) returns #t if the named field is mutable, #f otherwise. A field is immutable if it is not declared mutable or if the compiler optimizes away all assignments to the field.

(record-object 'set! name value) sets the value of the named field to value. An exception is raised with condition type &assertion if the named field is not assignable.

3.5. Locating objects

(make-object-finder pred) procedure
(make-object-finder pred g) procedure
(make-object-finder pred x g) procedure

returns: see below
libraranies: (chezscheme)

The procedure make-object-finder takes a predicate pred and two optional arguments: a starting point x and a maximum generation g. The starting point defaults to the value of the procedure oblist, and the maximum generation defaults to the value of the parameter collect-maximum-generation. make-object-finder returns an object finder p that can be used to search for objects satisfying pred within the starting-point object x. Immediate objects and objects in generations older than g are treated as leaves. p is a procedure accepting no arguments. If an object y satisfying pred can be found starting with x, p returns a list whose first element is y and whose remaining elements represent the path of objects from x to y, listed in reverse order. p can be invoked multiple times to find additional objects satisfying the predicate, if any. p returns #f if no more objects matching the predicate can be found.

p maintains internal state recording where it has been so it can restart at the point of the last found object and not return the same object twice. The state can be several times the size of the starting-point object x and all that is reachable from x.

The interactive inspector provides a convenient interface to the object finder in the form of find and find-next commands.

Relocation tables for static code objects are discarded by default, which prevents object finders from providing accurate results when static code objects are involved. That is, they will not find any objects pointed to directly from a code object that has been promoted to the static generation. If this is a problem, the command-line argument --retain-static-relocation can be used to prevent the relocation tables from being discarded.
3.6. Nested object size and composition

The procedures `compute-size` and `compute-composition` can be used to determine the size or composition of an object, including anything reachable via pointers from the object. Depending on the number of objects reachable from the object, the procedures potentially allocate a large amount of memory. In an application for which knowing the number, size, generation, and types of all objects in the heap is sufficient, `object-counts` is potentially much more efficient.

The procedure `compute-size-increments` is similar to `compute-size` mapped over a list of elements, but it reports a size for each later element without including the size of objects reachable from earlier elements, and it treats weak and ephemeron pairs differently. For a large number of reachable objects, `compute-size-increments` uses much less memory than `compute-size`.

These procedures treat immediate objects such as fixnums, booleans, and characters as zero-count, zero-byte leaves.

By default, these procedures also treat static objects (those in the initial heap) as zero-count, zero-byte leaves. Both procedures accept an optional second argument that specifies the maximum generation of interest, with the symbol `static` being used to represent the static generation.

Objects sometimes point to a great deal more than one might expect. For example, if static data is included, the procedure value of `(lambda (x) x)` points indirectly to the exception handling subsystem (because of the argument-count check) and many other things as a result of that.

Relocation tables for static code objects are discarded by default, which prevents these procedures from providing accurate results when static code objects are involved. That is, they will not find any objects pointed to directly from a code object that has been promoted to the static generation. If accurate sizes and compositions for static code objects are required, the command-line argument `--retain-static-relocation` can be used to prevent the relocation tables from being discarded.

```
(compute-size object)  procedure
(compute-size object generation)  procedure
returns: see below
libraries: (chezscheme)
```

`object` can be any object. `generation` must be a fixnum between 0 and the value of `collect-maximum-generation`, inclusive, or the symbol `static`. If `generation` is not supplied, it defaults to the value of `collect-maximum-generation`.

`compute-size` returns the amount of memory, in bytes, occupied by `object` and anything reachable from `object` in any generation less than or equal to `generation`. Immediate values such as fixnums, booleans, and characters have zero size. Size computation for a thread is limited when the thread is still active, since its full continuation cannot be inspected in that case, but the full continuation is inspected if the thread is inactive (such as during a garbage collection rendezvous when a different thread is selected by the rendezvous).
The following examples are valid for machines with 32-bit pointers.

\[
\begin{align*}
(\text{compute-size } 0) & \Rightarrow 0 \\
(\text{compute-size } (\text{cons } 0 0)) & \Rightarrow 8 \\
(\text{compute-size } (\text{cons } (\text{vector } \#t \ #f) 0)) & \Rightarrow 24 \\
(\text{compute-size} & \\
(\text{let } ([x (\text{cons } 0 0)]) & \\
(\text{set-car! } x x) & \\
(\text{set-cdr! } x x) & \Rightarrow 8 \\
(\text{x}) & \\
(\text{define-record-type} & \text{frob } (\text{fields } x)) & \\
(\text{collect } 1 \ 1); \text{force rtd into generation } 1 & \\
(\text{compute-size} & \\
(\text{let } ([x (\text{make-frob } 0)]) & \\
(\text{cons } x x)) & \Rightarrow 16 \\
0) & \\
\end{align*}
\]

\begin{itemize}
\item \text{(compute-composition} \text{object)} \quad \text{procedure}
\item \text{(compute-composition} \text{object generation)} \quad \text{procedure}
\end{itemize}

\text{returns: see below}

\text{libraries: (chezscheme)}

\text{object} can be any object. \text{generation} must be a fixnum between 0 and the value of \text{collect-maximum-generation}, inclusive, or the symbol \text{static}. If \text{generation} is not supplied, it defaults to the value of \text{collect-maximum-generation}.

\text{compute-composition} returns an association list representing the composition of \text{object}, including anything reachable from it in any generation less than or equal to \text{generation}. The association list has the following structure:

\begin{itemize}
\item \text{((type} \text{ count} \ 0 . \text{bytes}) \ldots)\)
\end{itemize}

\text{type} is either the name of a primitive type, represented as a symbol, e.g., \text{pair}, or a record-type descriptor (rtd). \text{count} and \text{bytes} are nonnegative fixnums.

Immediate values such as fixnums, booleans, and characters are not included in the composition.

The following examples are valid for machines with 32-bit pointers.

\[
\begin{align*}
(\text{compute-composition } 0) & \Rightarrow () \\
(\text{compute-composition } (\text{cons } 0 0)) & \Rightarrow ((\text{pair } 1 . 8)) \\
(\text{compute-composition} & \\
(\text{cons } (\text{vector } \#t \ #f) 0)) & \Rightarrow ((\text{pair } 1 . 8) (\text{vector } 1 . 16)) \\
(\text{compute-composition} & \\
(\text{let } ([x (\text{cons } 0 0)]) & \\
(\text{set-car! } x x) & \\
(\text{set-cdr! } x x) & \Rightarrow ((\text{pair } 1 . 8) \\
\text{x}))
\end{align*}
\]
(define-record-type frob (fields x))
(collect 1 1) ; force rtd into generation 1
(compute-composition
  (let ([x (make-frob 0)])
    (cons x x))
  0) ; force rtd into generation 1
⇒ ((pair 1 . 8)
    (#<record type frob> 1 . 8))

(compute-size-increments list) ; procedure
(compute-size-increments list generation) ; procedure
returns: a list as described below
libraries: (chezscheme)

list must be a list, but each element can be any object. generation must be a fixnum between 0 and the value of collect-maximum-generation, inclusive, or the symbol static. If generation is not supplied, it defaults to the value of collect-maximum-generation. In the threaded versions of Chez Scheme, the thread that invokes compute-size-increments must be the only active thread.

compute-size-increments is like mapping compute-size over list, except that any object reachable from an earlier element of list is not treated as reachable by a later element of list. In addition, each immediate element of list is not treated as reachable by earlier elements of list—although other values reachable from later elements of list may be considered reachable from earlier elements.

Unlike compute-size, compute-size-increments does not consider the car of a weak pair reachable from the weak pair. It also does not consider the car or cdr of an ephemeron pair to be reachable from the ephemeron pair, unless the car is already determined to be reachable (perhaps from an earlier element of list); if the car of an ephemeron pair is discovered to be reachable later (perhaps from a later element of list), then the cdr of the ephemeron pair is considered to be reachable from the car, which has the effect of charging the memory of the cdr to the same element of list as the memory of the car.

The following examples are valid for machines with 32-bit pointers.

(compute-size-increments (list 0)) ⇒ (0)
(compute-size-increments (list (cons 0 0))) ⇒ (8)
(compute-size-increments (list (cons 0 0) (cons 0 0))) ⇒ (8 8)
(compute-size-increments (let ([p (cons 0 0)])
    (list p p))) ⇒ (8 0)
(compute-size-increments (let ([p (cons 0 0)])
    (list (cons 1 p) (cons 1 p)))) ⇒ (16 8)
(compute-size-increments (list (ephemeron-cons 0 0))) ⇒ (16)
(compute-size-increments (let* ([p (cons 0 0)]
    [e (ephemeron-cons p (cons 0 0))])
    (list e p))) ⇒ (16 16)
4. Foreign Interface

Chez Scheme provides two ways to interact with “foreign” code, i.e., code written in other languages. The first is via subprocess creation and communication, which is discussed in the Section 4.1. The second is via static or dynamic loading and invocation from Scheme of procedures written in C and invocation from C of procedures written in Scheme. These mechanisms are discussed in Sections 4.2 through 4.4.

The method for static loading of C object code is dependent upon which machine you are running; see the installation instructions distributed with Chez Scheme.

4.1. Subprocess Communication

Two procedures, system and process, are used to create subprocesses. Both procedures accept a single string argument and create a subprocess to execute the shell command contained in the string. The system procedure waits for the process to exit before returning, however, while the process procedure returns immediately without waiting for the process to exit. The standard input and output files of a subprocess created by system may be used to communicate with the user’s console. The standard input and output files of a subprocess created by process may be used to communicate with the Scheme process.

(system command) procedure
returns: see below
libraries: (chezscheme)

command must be a string.

The system procedure creates a subprocess to perform the operation specified by command. The subprocess may communicate with the user through the same console input and console output files used by the Scheme process. After creating the subprocess, system waits for the process to exit before returning.

When the subprocess exits, system returns the exit code for the subprocess, unless (on Unix-based systems) a signal caused the subprocess to terminate, in which case system returns the negation of the signal that caused the termination, e.g., -1 for SIGHUP.
command must be a string. If ?transcoder is present and not #f, it must be a transcoder, and this procedure creates textual ports, each of whose transcoder is ?transcoder. Otherwise, this procedure returns binary ports. b-mode specifies the buffer mode used by each of the ports returned by this procedure and defaults to block. Buffer modes are described in Section 7.2 of The Scheme Programming Language, 4th Edition.

open-process-ports creates a subprocess to perform the operation specified by command. Unlike system, process returns immediately after creating the subprocess, i.e., without waiting for the subprocess to terminate. It returns four values:

1. to-stdin is an output port to which Scheme can send output to the subprocess through the subprocess’s standard input file.
2. from-stdout is an input port from which Scheme can read input from the subprocess through the subprocess’s standard output file.
3. from-stderr is an input port from which Scheme can read input from the subprocess through the subprocess’s standard error file.
4. process-id is an integer identifying the created subprocess provided by the host operating system.

If the process exits or closes its standard output file descriptor, any procedure that reads input from from-stdout will return an end-of-file object. Similarly, if the process exits or closes its standard error file descriptor, any procedure that reads input from from-stderr will return an end-of-file object.

The predicate input-port-ready? may be used to detect whether input has been sent by the subprocess to Scheme.

It is sometimes necessary to force output to be sent immediately to the subprocess by invoking flush-output-port on to-stdin, since Chez Scheme buffers the output for efficiency.

On UNIX systems, the process-id is the process identifier for the shell created to execute command. If command is used to invoke an executable file rather than a shell command, it may be useful to prepend command with the string "exec ", which causes the shell to load and execute the named executable directly, without forking a new process—the shell equivalent of a tail call. This will reduce by one the number of subprocesses created and cause process-id to reflect the process identifier for the executable once the shell has transferred control.
process is similar to open-process-ports, but less general. It does not return a port from which the subprocess’s standard error output can be read, and it always creates textual ports. It returns a list of three values rather than the four separate values of open-process-ports. The returned list contains, in order: from-stdout, to-stdin, and process-id, which correspond to the second, first, and fourth return values of open-process-ports.

4.2. Calling out of Scheme

Chez Scheme’s foreign-procedure interface allows a Scheme program to invoke procedures written in C or in languages that obey the same calling conventions as C. Two steps are necessary before foreign procedures can be invoked from Scheme. First, the foreign procedure must be compiled and loaded, either statically or dynamically, as described in Section 4.7. Then, access to the foreign procedure must be established in Scheme, as described in this section. Once access to a foreign procedure has been established it may be called as an ordinary Scheme procedure.

Since foreign procedures operate independently of the Scheme memory management and exception handling system, great care must be taken when using them. Although the foreign-procedure interface provides type checking (at optimize levels less than 3) and type conversion, the programmer must ensure that the sharing of data between Scheme and foreign procedures is done safely by specifying proper argument and result types.

Scheme-callable wrappers for foreign procedures can also be created via ftype-ref and function ftypes (Section 4.5).

\[
\text{(foreign-procedure conv \ldots entry-exp (param-type \ldots) res-type)}
\]

**Syntax**

returns: a procedure

libraries: (chezscheme)

*entry-exp* must evaluate to a string representing a valid foreign procedure entry point or an integer representing the address of the foreign procedure. The *param-types* and *res-type* must be symbols or structured forms as described below. When a foreign-procedure expression is evaluated, a Scheme procedure is created that will invoke the foreign procedure specified by *entry-exp*. When the procedure is called each argument is checked and converted according to the specified *param-type* before it is passed to the foreign procedure. The result of the foreign procedure call is converted as specified by the *res-type*. Multiple procedures may be created for the same foreign entry.

Each *conv* adjusts the calling convention to be used. A #f is allowed as *conv* to indicate the default calling convention on the target machine (so the #f has no effect). Three other conventions are currently supported under Windows: __stdcall, __cdecl, and __com (32-bit only). Since __cdecl is the default, specifying __cdecl is equivalent to specifying #f or no convention. Additionally, *conv* can be __collect_safe to indicate that garbage collection is allowed concurrently with a call of the foreign procedure, or it can be __varargs or (__varargs_after n) to indicate that the procedure uses a convention that works with a variable number of arguments after the first n (which may differ from the convention...
used for the fixed-argument variant on some platforms and conventions). \texttt{__varargs} is a shorthand for (\texttt{__varargs\_after 1}).

Use \texttt{__stdcall} to access most Windows API procedures. Use \texttt{__cdecl} for Windows API varargs procedures, for C library procedures, and for most other procedures. Use \texttt{__com} to invoke COM interface methods; COM uses the \texttt{__stdcall} convention but additionally performs the indirections necessary to obtain the correct method from a COM instance. The address of the COM instance must be passed as the first argument, which should normally be declared as \texttt{iptr}. For the \texttt{__com} interface only, \texttt{entry-exp} must evaluate to the byte offset of the method in the COM vtable. For example,

\begin{verbatim}
(foreign-procedure __com 12 (iptr double-float) integer-32)
\end{verbatim}

creates an interface to a COM method at offset 12 in the vtable encapsulated within the COM instance passed as the first argument, with the second argument being a double float and the return value being an integer.

Use \texttt{__collect\_safe} to declare that garbage collection is allowed concurrently with the foreign procedure. The \texttt{__collect\_safe} declaration allows concurrent collection by deactivating the current thread (see \texttt{fork-thread}) when the foreign procedure is called, and the thread is activated again when the foreign procedure returns. The \texttt{__collect\_safe} declaration is useful, for example, when calling a blocking I/O call to allow other Scheme threads to run normally. Refrain from passing collectable memory to a \texttt{__collect\_safe} foreign procedure, or use \texttt{lock-object} to lock the memory in place; see also \texttt{Sdeactivate\_thread}. The \texttt{__collect\_safe} declaration has no effect on a non-threaded version of the system.

For example, calling the C \texttt{sleep} function with the default convention will block other Scheme threads from performing a garbage collection, but adding the \texttt{__collect\_safe} declaration avoids that problem:

\begin{verbatim}
(define c-sleep
  (foreign-procedure __collect_safe "sleep" (unsigned) unsigned))
(c-sleep 10) ; sleeps for 10 seconds without blocking other threads
\end{verbatim}

If a foreign procedure that is called with \texttt{__collect\_safe} can invoke callables, then each callable should also be declared with \texttt{__collect\_safe} so that the callable reactivates the thread.

Complete type checking and conversion is performed on the parameters to a foreign procedure. The types \texttt{scheme-object}, \texttt{string}, \texttt{wstring}, \texttt{u8*}, \texttt{u16*}, \texttt{u32*}, \texttt{utf-8}, \texttt{utf-16}, \texttt{utf-16le}, \texttt{utf-16be}, \texttt{utf-32}, \texttt{utf-32le}, and \texttt{utf-32be}, must be used with caution, however, since they allow allocated Scheme objects to be used in places the Scheme memory management system cannot control. No problems will arise as long as such objects are not retained in foreign variables or data structures while Scheme code is running, and as long as they are not passed as arguments to a \texttt{__collect\_safe} procedure, since garbage collection can occur only while Scheme code is running or when concurrent garbage collection is enabled. Other parameter types are converted to equivalent foreign representations and consequently they can be retained indefinitely in foreign variables and data structures.

For argument types \texttt{string}, \texttt{wstring}, \texttt{utf-8}, \texttt{utf-16}, \texttt{utf-16le}, \texttt{utf-16be}, \texttt{utf-32}, \texttt{utf-32le}, and \texttt{utf-32be}, an argument is converted to a fresh object that is passed to
the foreign procedure. Since the fresh object is not accessible for locking before the call, it can never be treated correctly for a \_\_collect\_safe foreign procedure, so those types are disallowed as argument types for a \_\_collect\_safe foreign procedure. For analogous reasons, those types are disallowed as the result of a \_\_collect\_safe foreign callable.

Following are the valid parameter types:

**integer-8:** Exact integers from $-2^7$ through $2^8 - 1$ are valid. Integers in the range $2^7$ through $2^8 - 1$ are treated as two’s complement representations of negative numbers, e.g., \#xff is treated as $-1$. The argument is passed to C as an integer of the appropriate size (usually **signed char**).

**unsigned-8:** Exact integers from $-2^7$ to $2^8 - 1$ are valid. Integers in the range $-2^7$ through $-1$ are treated as the positive equivalents of their two’s complement representation, e.g., $-1$ is treated as \#xff. The argument is passed to C as an unsigned integer of the appropriate size (usually **unsigned char**).

**integer-16:** Exact integers from $-2^{15}$ through $2^{16} - 1$ are valid. Integers in the range $2^{15}$ through $2^{16} - 1$ are treated as two’s complement representations of negative numbers, e.g., \#xffff is treated as $-1$. The argument is passed to C as an integer of the appropriate size (usually **short**).

**unsigned-16:** Exact integers from $-2^{15}$ to $2^{16} - 1$ are valid. Integers in the range $-2^{15}$ through $-1$ are treated as the positive equivalents of their two’s complement representation, e.g., $-1$ is treated as \#xffff. The argument is passed to C as an unsigned integer of the appropriate size (usually **unsigned short**).

**integer-32:** Exact integers from $-2^{31}$ through $2^{32} - 1$ are valid. Integers in the range $2^{31}$ through $2^{32} - 1$ are treated as two’s complement representations of negative numbers, e.g., \#ffffffff is treated as $-1$. The argument is passed to C as an integer of the appropriate size (usually **int**).

**unsigned-32:** Exact integers from $-2^{31}$ to $2^{32} - 1$ are valid. Integers in the range $-2^{31}$ through $-1$ are treated as the positive equivalents of their two’s complement representation, e.g., $-1$ is treated as \#ffffffff. The argument is passed to C as an unsigned integer of the appropriate size (usually **unsigned int**).

**integer-64:** Exact integers from $-2^{63}$ through $2^{64} - 1$ are valid. Integers in the range $2^{63}$ through $2^{64} - 1$ are treated as two’s complement representations of negative numbers. The argument is passed to C as an integer of the appropriate size (usually **long long** or, on many 64-bit platforms, **long**).

**unsigned-64:** Exact integers from $-2^{63}$ through $2^{64} - 1$ are valid. Integers in the range $-2^{63}$ through $-1$ are treated as the positive equivalents of their two’s complement representation, The argument is passed to C as an integer of the appropriate size (usually **unsigned long long** or, on many 64-bit platforms, **long**).

**double-float:** Only Scheme flonums are valid—other Scheme numeric types are not automatically converted. The argument is passed to C as a double float.
4. Foreign Interface

**single-float**: Only Scheme flonums are valid—other Scheme numeric types are not automatically converted. The argument is passed to C as a single float. Since Chez Scheme represents flonums in double-float format, the parameter is first converted into single-float format.

**short**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C `short`.

**unsigned-short**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C `unsigned short`.

**int**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C `int`.

**unsigned**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C `unsigned`.

**unsigned-int**: This type is an alias `unsigned` fixed-size type above, depending on the size of a C `unsigned`.

**long**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C `long`.

**unsigned-long**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C `unsigned long`.

**long-long**: This type is an alias for the appropriate fixed-size type above, depending on the size of the nonstandard C type `long long`.

**unsigned-long-long**: This type is an alias for the appropriate fixed-size type above, depending on the size of the nonstandard C type `unsigned long long`.

**ptrdiff_t**: This type is an alias for the appropriate fixed-size type above, depending on its definition in the host machine’s `stddef.h` include file.

**size_t**: This type is an alias for the appropriate unsigned fixed-size type above, depending on its definition in the host machine’s `stddef.h` include file.

**ssize_t**: This type is an alias for the appropriate signed fixed-size type above, depending on its definition in the host machine’s `stddef.h` include file.

**iptr**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C pointer.

**uptr**: This type is an alias for the appropriate (unsigned) fixed-size type above, depending on the size of a C pointer.

**void**: This type is an alias for `uptr`.
4.2. Calling out of Scheme

fixnum: This type is equivalent to iptr, except only values in the fixnum range are valid. Transmission of fixnums is slightly faster than transmission of iptr values, but the fixnum range is smaller, so some iptr values do not have a fixnum representation.

boolean: Any Scheme object may be passed as a boolean. #f is converted to 0; all other objects are converted to 1. The argument is passed to C as an int.

char: Only Scheme characters with Unicode scalar values in the range 0 through 255 are valid char parameters. The character is converted to its Unicode scalar value, as with char->integer, and passed to C as an unsigned char.

wchar_t: Only Scheme characters are valid wchar_t parameters. Under Windows and any other system where wchar_t holds only 16-bit values rather than full Unicode scalar values, only characters with 16-bit Unicode scalar values are valid. On systems where wchar_t is a full 32-bit value, any Scheme character is valid. The character is converted to its Unicode scalar value, as with char->integer, and passed to C as a wchar_t.

wchar: This type is an alias for wchar_t.

double: This type is an alias for double-float.

float: This type is an alias for single-float.

scheme-object: The argument is passed directly to the foreign procedure; no conversion or type checking is performed. This form of parameter passing should be used with discretion. Scheme objects should not be preserved in foreign variables or data structures since the memory management system may relocate them between foreign procedure calls.

ptr: This type is an alias for scheme-object.

u8*: The argument must be a Scheme bytevector or #f. For #f, the null pointer (0) is passed to the foreign procedure. For a bytevector, a pointer to the first byte of the bytevector’s data is passed. If the C routine to which the data is passed requires the input to be null-terminated, a null (0) byte must be included explicitly in the bytevector. The bytevector should not be retained in foreign variables or data structures, since the memory management system may relocate or discard them between foreign procedure calls, and use their storage for some other purpose.

u16*: Arguments of this type are treated just like arguments of type u8*. If the C routine to which the data is passed requires the input to be null-terminated, two null (0) bytes must be included explicitly in the bytevector, aligned on a 16-bit boundary.

u32*: Arguments of this type are treated just like arguments of type u8*. If the C routine to which the data is passed requires the input to be null-terminated, four null (0) bytes must be included explicitly in the bytevector, aligned on a 32-bit boundary.

utf-8: The argument must be a Scheme string or #f. For #f, the null pointer (0) is passed to the foreign procedure. A string is converted into a bytevector, as if via string->utf8,
with an added null byte, and the address of the first byte of the bytevector is passed to C. The bytevector should not be retained in foreign variables or data structures, since the memory management system may relocate or discard them between foreign procedure calls and use their storage for some other purpose. The utf-8 argument type is not allowed for a __collect_safe foreign procedure.

**utf-16**: Arguments of this type are treated like arguments of type utf-8, except they are converted as if via string->utf16 with endianness (native-endianness), and they are extended by two null bytes rather than one.

**utf-16le**: Arguments of this type are treated like arguments of type utf-8, except they are converted as if via string->utf16 with endianness little, and they are extended by two null bytes rather than one.

**utf-16be**: Arguments of this type are treated like arguments of type utf-8, except they are converted as if via string->utf16 with endianness big, and they are extended by two null bytes rather than one.

**utf-32**: Arguments of this type are treated like arguments of type utf-8, except they are converted as if via string->utf32 with endianness (native-endianness), and they are extended by four null bytes rather than one.

**utf-32le**: Arguments of this type are treated like arguments of type utf-8, except they are converted as if via string->utf32 with endianness little, and they are extended by four null bytes rather than one.

**utf-32be**: Arguments of this type are treated like arguments of type utf-8, except they are converted as if via string->utf32 with endianness big, and they are extended by four null bytes rather than one.

**string**: This type is an alias for utf-8.

**wstring**: This type is an alias for utf-16 or utf-32 as appropriate depending on the size of a C wchar_t. For example, wstring is equivalent to utf-16 under Windows running on Intel hardware.

(* ftype-name): This type allows a pointer to a foreign type (ftype) to be passed. The argument must be an ftype pointer of the type identified by ftype-name, and the actual argument is the address encapsulated in the ftype pointer. See Section 4.5 for a description of foreign types.

(& ftype-name): This type allows a foreign type (ftype) to be passed as a value, but represented on the Scheme side as a pointer to the foreign-type data. That is, a (& ftype-name) argument is represented on the Scheme side the same as a (* ftype-name) argument, but a (& ftype-name) argument is passed to the foreign procedure as the content at the foreign pointer’s address instead of as the address. For example, if ftype-name identifies a struct type, then (& ftype-name) passes a struct argument instead of a struct-pointer argument. The ftype-name cannot refer to an array type.
4.2. Calling out of Scheme

The result types are similar to the parameter types with the addition of a void type. In general, the type conversions are the inverse of the parameter type conversions. No error checking is performed on return, since the system cannot determine whether a foreign result is actually of the indicated type. Particular caution should be exercised with the result types scheme-object, double-float, double, single-float, float, and the types that result in the construction of bytevectors or strings, since invalid return values may lead to invalid memory references as well as incorrect computations. Following are the valid result types:

**void**: The result of the foreign procedure call is ignored and an unspecified Scheme object is returned. void should be used when foreign procedures are called for effect only.

**integer-8**: The result is interpreted as a signed 8-bit integer and is converted to a Scheme exact integer.

**unsigned-8**: The result is interpreted as an unsigned 8-bit integer and is converted to a Scheme nonnegative exact integer.

**integer-16**: The result is interpreted as a signed 16-bit integer and is converted to a Scheme exact integer.

**unsigned-16**: The result is interpreted as an unsigned 16-bit integer and is converted to a Scheme nonnegative exact integer.

**integer-32**: The result is interpreted as a signed 32-bit integer and is converted to a Scheme exact integer.

**unsigned-32**: The result is interpreted as an unsigned 32-bit integer and is converted to a Scheme nonnegative exact integer.

**integer-64**: The result is interpreted as a signed 64-bit integer and is converted to a Scheme exact integer.

**unsigned-64**: The result is interpreted as an unsigned 64-bit integer and is converted to a Scheme nonnegative exact integer.

**double-float**: The result is interpreted as a double float and is translated into a Chez Scheme flonum.

**single-float**: The result is interpreted as a single float and is translated into a Chez Scheme flonum. Since Chez Scheme represents flonums in double-float format, the result is first converted into double-float format.

**short**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C short.

**unsigned-short**: This type is an alias for the appropriate fixed-size type above, depending on the size of a C unsigned short.
int: This type is an alias for the appropriate fixed-size type above, depending on the size of a C int.

unsigned: This type is an alias for the appropriate fixed-size type above, depending on the size of a C unsigned.

unsigned-int: This type is an alias unsigned. fixed-size type above, depending on the size of a C unsigned.

long: This type is an alias for the appropriate fixed-size type above, depending on the size of a C long.

unsigned-long: This type is an alias for the appropriate fixed-size type above, depending on the size of a C unsigned long.

long-long: This type is an alias for the appropriate fixed-size type above, depending on the size of the nonstandard C type long long.

unsigned-long-long: This type is an alias for the appropriate fixed-size type above, depending on the size of the nonstandard C type unsigned long long.

ptrdiff_t: This type is an alias for the appropriate fixed-size type above, depending on its definition in the host machine’s stddef.h include file.

size_t: This type is an alias for the appropriate unsigned fixed-size type above, depending on its definition in the host machine’s stddef.h include file.

ssize_t: This type is an alias for the appropriate signed fixed-size type above, depending on its definition in the host machine’s stddef.h include file.

iptr: This type is an alias for the appropriate fixed-size type above, depending on the size of a C pointer.

uptr: This type is an alias for the appropriate (unsigned) fixed-size type above, depending on the size of a C pointer.

void*: This type is an alias for uptr.

boolean: This type converts a C int return value into a Scheme boolean. 0 is converted to #f; all other values are converted to #t.

char: This type converts a C unsigned char return value into a Scheme character, as if via integer->char.

wchar_t: This type converts a C wchar_t return value into a Scheme character, as if via integer->char. The wchar_t value must be a valid Unicode scalar value.

wchar: This type is an alias for wchar_t.

double: This type is an alias for double-float.
4.2. Calling out of Scheme

**float**: This type is an alias for **single-float**.

**scheme-object**: The result is assumed to be a valid Scheme object, and no conversion is performed. This type is inherently dangerous, since an invalid Scheme object can corrupt the memory management system with unpredictable (but always unpleasant) results. Since Scheme objects are actually typed pointers, even integers cannot safely be returned as type **scheme-object** unless they were created by the Scheme system.

**ptr**: This type is an alias for **scheme-object**.

**u8***: The result is interpreted as a pointer to a null-terminated sequence of 8-bit unsigned integers (bytes). If the result is a null pointer, **#f** is returned. Otherwise, the sequence of bytes is stored in a freshly allocated bytevector of the appropriate length, and the bytevector is returned to Scheme.

**u16***: The result is interpreted as a pointer to a null-terminated sequence of 16-bit unsigned integers. If the result is a null pointer, **#f** is returned. Otherwise, the sequence of 16-bit integers is stored in a freshly allocated bytevector of the appropriate length, and the bytevector is returned to Scheme. The null terminator must be a properly aligned 16-bit word, i.e., two bytes of zero aligned on a 16-bit boundary.

**u32***: The result is interpreted as a pointer to a null-terminated sequence of 32-bit unsigned integers. If the result is a null pointer, **#f** is returned. Otherwise, the sequence of 16-bit integers is stored in a freshly allocated bytevector of the appropriate length, and the bytevector is returned to Scheme. The null terminator must be a properly aligned 32-bit word, i.e., four bytes of zero aligned on a 32-bit boundary.

**utf-8**: The result is interpreted as a pointer to a null-terminated sequence of 8-bit unsigned character values. If the result is a null pointer, **#f** is returned. Otherwise, the sequence of bytes is converted into a Scheme string, as if via **utf8->string**, and the string is returned to Scheme.

**utf-16**: The result is interpreted as a pointer to a null-terminated sequence of 16-bit unsigned integers. If the result is a null pointer, **#f** is returned. Otherwise, the sequence of integers is converted into a Scheme string, as if via **utf16->string** with endianness **native-endianness**, and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.

**utf-16le**: The result is interpreted as a pointer to a null-terminated sequence of 16-bit unsigned integers. If the result is a null pointer, **#f** is returned. Otherwise, the sequence of integers is converted into a Scheme string, as if via **utf16->string** with endianness **little**, and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.

**utf-16be**: The result is interpreted as a pointer to a null-terminated sequence of 16-bit unsigned integers. If the result is a null pointer, **#f** is returned. Otherwise, the sequence of integers is converted into a Scheme string, as if via **utf16->string** with endianness **big**, and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.
and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.

**utf-32**: The result is interpreted as a pointer to a null-terminated sequence of 32-bit unsigned integers. If the result is a null pointer, \#f is returned. Otherwise, the sequence of integers is converted into a Scheme string, as if via `utf32->string` with endianness (native-endianness), and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.

**utf-32le**: The result is interpreted as a pointer to a null-terminated sequence of 32-bit unsigned integers. If the result is a null pointer, \#f is returned. Otherwise, the sequence of integers is converted into a Scheme string, as if via `utf32->string` with endianness little, and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.

**utf-32be**: The result is interpreted as a pointer to a null-terminated sequence of 32-bit unsigned integers. If the result is a null pointer, \#f is returned. Otherwise, the sequence of integers is converted into a Scheme string, as if via `utf32->string` with endianness big, and the string is returned to Scheme. A byte-order mark in the sequence of integers is treated as an ordinary character value and does not affect the byte ordering.

**string**: This type is an alias for utf-8.

**wstring**: This type is an alias for utf-16 or utf-32 as appropriate depending on the size of a C wchar_t. For example, wstring is equivalent to utf-16 under Windows running on Intel hardware.

(** ftype-name)**: The result is interpreted as the address of a foreign object whose structure is described by the ftype identified by `ftype-name`, and a freshly allocated ftype pointer encapsulating the address is returned. See Section 4.5 for a description of foreign types.

&( **ftype-name)**: The result is interpreted as a foreign object whose structure is described by the ftype identified by `ftype-name`, where the foreign procedure returns a `ftype-name` result, but the caller must provide an extra (** ftype-name**) argument before all other arguments to receive the result. An unspecified Scheme object is returned when the foreign procedure is called, since the result is instead written into storage referenced by the extra argument. The `ftype-name` cannot refer to an array type.

Consider a C identity procedure:

```c
int id(x) int x; { return x; }
```

After a file containing this procedure has been compiled and loaded (see Section 4.7) it can be accessed as follows:
(foreign-procedure "id"
  (int) int) ⇒ #<procedure>
((foreign-procedure "id"
    (int) int)
  1) ⇒ 1
(define int-id
  (foreign-procedure "id"
    (int) int))
(int-id 1) ⇒ 1

The "id" entry can also be interpreted as accepting and returning a boolean:

(define bool-id
  (foreign-procedure "id"
    (boolean) boolean))
(bool-id #f) ⇒ #f
(bool-id #t) ⇒ #t
(bool-id 1) ⇒ #t

As the last example reveals, bool-id is actually a conversion procedure. When a Scheme object is passed as type boolean it is converted to 0 or 1, and when it is returned it is converted to #f or #t. As a result objects are converted to normalized boolean values. The "id" entry can be used to create other conversion procedures by varying the type specifications:

(define int->bool
  (foreign-procedure "id"
    (int) boolean))
(int->bool 0) ⇒ #f
(int->bool 5) ⇒ #t
(map (foreign-procedure "id"
    (boolean) int)
  ,( #t #f)) ⇒ (1 0)
(define void
  (foreign-procedure "id"
    (int) void))
(void 10) ⇒ unspecified

There are, of course, simpler and more efficient ways of accomplishing these conversions directly in Scheme.

A foreign entry is resolved when a foreign-procedure expression is evaluated, rather than either when the code is loaded or each time the procedure is invoked. Thus, the following definition is always valid since the foreign-procedure expression is not immediately evaluated:

(define doit
  (lambda ()
    ((foreign-procedure "doit" () void))))

doit should not be invoked, however, before an entry for "doit" has been provided. Simi-
larly, an entry for "doit" must exist before the following code is evaluated:

```
(define doit
  (foreign-procedure "doit" () void))
```

Although the second definition is more constraining on the load order of foreign files, it is more efficient since the entry resolution need be done only once.

It is often useful to define a template to be used in the creation of several foreign procedures with similar argument types and return values. For example, the following code creates two foreign procedures from a single foreign procedure expression, by abstracting out the foreign procedure name:

```
(define double->double
  (lambda (proc-name)
    (foreign-procedure proc-name
      (double)
      double)))

(define log10 (double->double "log10"))
(define gamma (double->double "gamma"))
```

Both "log10" and "gamma" must be available as foreign entries (see Section 4.7) before the corresponding definitions. The use of foreign procedure templates can simplify the coding process and reduce the amount of code generated when a large number of foreign procedures are involved, e.g., when an entire library of foreign procedures is imported into Scheme.

### 4.3. Calling into Scheme

Section 4.2 describes the `foreign-procedure` form, which permits Scheme code to invoke C or C-compatible foreign procedures. This section describes the `foreign-callable` form, which permits C or C-compatible code to call Scheme procedures. A more primitive mechanism for calling Scheme procedures from C is described in Section 4.9.

As when calling foreign procedures from Scheme, great care must be taken when sharing data between Scheme and foreign code that calls Scheme to avoid corrupting Scheme’s memory management system.

A foreign-callable wrapper for a Scheme procedure can also be created by passing the procedure to `make-ftype-pointer` with an appropriate function `ftype` (Section 4.5).

```
(foreign-callable conv ... proc-exp (param-type ...) res-type) syntax
returns: a code object
libraries: (chezscheme)
```

`proc-exp` must evaluate to a procedure, the Scheme procedure that is to be invoked by foreign code. The parameter and result types are as described for `foreign-procedure` in Section 4.2 except that the requirements and conversions are effectively reversed, e.g., the con-
4.3. Calling into Scheme

versions described for foreign-procedure arguments are performed for foreign-callable return values. A (\& ftype) argument to the callable refers to an address that is valid only during the dynamic extent of the callback invocation. A (\& ftype) result type for a callable causes the Scheme procedure to receive an extra (\& ftype) argument before all others; the Scheme procedure should write a result into the extra argument, and the direct result of the Scheme procedure is ignored. Type checking is performed for result values but not argument values, since the parameter values are provided by the foreign code and must be assumed to be correct.

Each conv adjusts the calling convention to be used. foreign-callable supports the same conventions as foreign-procedure with the exception of __com. The __collect_safe convention for a callable activates a calling thread if the thread is not already activated, and the thread’s activation state is reverted when the callable returns. If a calling thread is not currently registered with the Scheme system, then reverting the thread’s activation state implies destroying the thread’s registration (see Sdestroy_thread).

The value produced by foreign-callable is a Scheme code object, which contains some header information as well as code that performs the call to the encapsulated Scheme procedure. The code object may be converted into a foreign-callable address via foreign-callable-entry-point, which returns an integer representing the address of the entry point within the code object. (The C-callable library function Sforeign_callable_entry_point, described in Section 4.9, may be used to obtain the entry point as well.) This is an implicit pointer into an immobile Scheme object, so it will not be relocated by the storage management system, but it may be reclaimed if the code object becomes unreachable on the Scheme side; lock the code object (using lock-object) or otherwise retain it if the entry point is, for example, registered as a callback and retained in the “C” side indefinitely.

The following code creates a foreign-callable code object, locks the code object, and returns the entry point.

(let ([x (foreign-callable
        (lambda (x y) (pretty-print (cons x (* y 2))))
        (string integer-32)
        void)])
  (lock-object x)
  (foreign-callable-entry-point x))

Unless the entry point is intended to be permanent, however, a pointer to the code object returned by foreign-callable should be retained (in which case locking is unnecessary, since the storage management system will not move the code object as long as it remains reachable on the Scheme side).

Mixed use of foreign-callable and foreign-procedure may result in nesting of foreign and Scheme calls, and this results in some interesting considerations when continuations are involved, directly or indirectly (as via the default exception handler). See Section 4.4 for a discussion of the interaction between foreign calls and continuations.

The following example demonstrates how the “callback” functions required by many windowing systems might be defined in Scheme with the use of foreign-callable. Assume
that the following C code has been compiled and loaded (see Section 4.7).

```c
#include <stdio.h>

typedef void (*CB)(char);

CB callbacks[256];

void cb_init(void) {
    int i;
    for (i = 0; i < 256; i += 1)
        callbacks[i] = (CB)0;
}

void register_callback(char c, CB cb) {
    callbacks[c] = cb;
}

void event_loop(void) {
    CB f; char c;
    for (;;) {
        c = getchar();
        if (c == EOF) break;
        f = callbacks[c];
        if (f != (CB)0) f(c);
    }
}
```

Interfaces to these functions may be defined in Scheme as follows.

```scheme
(define cb-init
    (foreign-procedure "cb_init" () void))
(define register-callback
    (foreign-procedure "register_callback" (char void*) void))
(define event-loop
    (foreign-procedure "__collect_safe" "event_loop" () void))
```

A callback for selected characters can then be defined.

```scheme
(define callback
    (lambda (p)
        (let ([code (foreign-callable "__collect_safe" p (char) void)])
            (lock-object code)
            (foreign-callable-entry-point code))))
(define ouch
    (callback
        (lambda (c)
            (printf "Ouch! Hit by ‘-c’-%c’" c))))
(define rats
    (callback
        (lambda (c)
4.4. Continuations and Foreign Calls

This sets up the following interaction.

> (event-loop)
a
Ouch! Hit by 'a'
b
c
Rats! Received 'c'
d
e
Ouch! Hit by 'e'

The __collect_safe declarations in this example ensure that other threads can continue working while event-loop blocks waiting for input. A more well-behaved version of the example would save each code object returned by foreign-callable and unlock it when it is no longer registered as a callback.

(foreign-callable-entry-point code) procedure
returns: the address of the foreign-callable entry point in code
libraries: (chezscheme)

code should be a code object produced by foreign-callable.

(foreign-callable-code-object address) procedure
returns: the code object corresponding to the foreign-callable entry point address
libraries: (chezscheme)

address must be an exact integer and should be the address of the entry point of a code object produced by foreign-callable.

4.4. Continuations and Foreign Calls

foreign-callable and foreign-procedure allow arbitrary nesting of foreign and Scheme calls. Because other languages do not support the fully general first-class continuations of Scheme, the interaction between continuations and nested calls among Scheme and foreign procedures is problematic. Chez Scheme handles this interaction in a general manner by trapping attempts to return to stale foreign contexts rather than by restricting the use of continuations directly. A foreign context is a foreign frame and return point corresponding to a particular call from a foreign language, e.g., C, into Scheme. A foreign context becomes
stale after a normal return to the context or after a return to some other foreign context
beneath it on the control stack.

As a result of this treatment, Scheme continuations may be used to throw control either
upwards or downwards logically through any mix of Scheme and foreign frames. Furthermore,
until some return to a foreign context is actually performed, all return points remain
valid. In particular, this means that programs that use continuations exclusively for non-
local exits never attempt to return to a stale foreign context. (Nonlocal exits themselves
are no problem and are implemented by the C library function `longjmp` or the equivalent.)
Programs that use continuations more generally also function properly as long as they
never actually return to a stale foreign context, even if control logically moves past stale
foreign contexts via invocation of continuations.

One implication of this mechanism is that the C stack pointer is not automatically restored
to its base value when a continuation is used on the Scheme side to perform a nonlocal
exit. If the program continues to run after the nonlocal exit, any further build-up of
the C stack will add to the existing build up, which might result in a C stack overflow.
To avoid this situation, a program can arrange to set up a single C call frame before
obtaining the continuation and return to the C frame after the nonlocal exit. The procedure
`with-exit-proc` below arranges to do this without involving any C code.

```lisp
(define with-exit-proc
  (lambda (p)
    (define th (lambda () (call/cc p)))
    (define-ftype -&gt;ptr (function () ptr))
    (let ([fptr (make-ftype-pointer -&gt;ptr th)])
      (let ([v ((ftype-ref -&gt;ptr () fptr))]
        (unlock-object
          (foreign-callable-code-object
            (ftype-pointer-address fptr)))
        v))))
```

`with-exit-proc` behaves like `call/cc` except it resets the C stack when the continuation
is invoked. To do this, it creates an ftype-pointer representing a foreign-callable entry
point for `th` and creates a Scheme-callable procedure for that entry point. This creates
a wrapper for `th` that involves a C call. When a call to the wrapper returns, either by
explicit invocation of the continuation passed to `p` or by a normal return from `p`, the C
stack is reset to its original value.

4.5. Foreign Data

The procedures described in this section directly create and manipulate foreign data, i.e.,
data that resides outside of the Scheme heap. With the exception of `foreign-alloc`,
`foreign-sizeof`, and `foreign-alignof`, these procedures are inherently unsafe in the sense
that they do not (and cannot) check the validity of the addresses they are passed. Improper
use of these procedures can result in invalid memory references, corrupted data, or system
crashes.
This section also describes a higher-level syntactic mechanism for manipulating foreign data, including foreign structures, unions, arrays, and bit fields. The syntactic interface is safer than the procedural interface but must still assume that the addresses it’s given are appropriate for the types of object being manipulated.

\[
\begin{align*}
(\text{foreign-alloc } n) \quad & \text{procedure} \\
\text{returns: the address of a freshly allocated block of foreign data } n \text{ bytes long} \\
\text{libraries: (chezscheme)}
\end{align*}
\]

\( n \) must be a positive fixnum. The returned value is an exact integer and is guaranteed to be properly aligned for any type of value according to the requirements of the underlying hardware. An exception is raised with condition type \text{assertion} if the block of foreign data cannot be allocated.

\[
\begin{align*}
(\text{foreign-free } address) \quad & \text{procedure} \\
\text{returns: unspecified} \\
\text{libraries: (chezscheme)}
\end{align*}
\]

This procedure frees the block of storage to which \( address \) points. \( address \) must be an exact integer in the range \(-2^w - 1\) through \(2^w - 1\), where \( w \) is the width in bits of a pointer, e.g., 64 for a 64-bit machine. It should be an address returned by an earlier call to \text{foreign-alloc} and not subsequently passed to \text{foreign-free}.

\[
\begin{align*}
(\text{foreign-ref } type \ address \ offset) \quad & \text{procedure} \\
\text{returns: see below} \\
\text{libraries: (chezscheme)}
\end{align*}
\]

\text{foreign-ref} extracts the value of type \( type \) from the memory location at \( offset \) bytes offset from \( address \).

\( type \) must be a symbol identifying the type of value to be extracted. The following types have machine-dependent sizes and correspond to the like-named C types:

- short,
- unsigned-short,
- int,
- unsigned,
- unsigned-int,
- long,
- unsigned-long,
- long-long,
- unsigned-long-long,
- ptrdiff_t,
- size_t,
• ssize_t,
• char,
• wchar_t,
• float,
• double, and
• void*.

The types long-long and unsigned-long-long correspond to the C types long long and unsigned long long. A value of type char is referenced as a single byte and converted (as if via integer->char) into a Scheme character. A value of type wchar_t is converted (as if via integer->char) into a Scheme character. The value must be a valid Unicode scalar value.

wchar is an alias for wchar_t.

Several additional machine-dependent types are recognized:

• iptr,
• uptr,
• fixnum, and
• boolean.

uptr is equivalent to void*; both are treated as unsigned integers the size of a pointer. iptr is treated as a signed integer the size of a pointer. fixnum is treated as an iptr, but with a range limited to the fixnum range. boolean is treated as an int, with zero converted to the Scheme value #f and all other values converted to #t.

Finally, several fixed-sized types are also supported:

• integer-8,
• unsigned-8,
• integer-16,
• unsigned-16,
• integer-32,
• unsigned-32,
• integer-64,
• unsigned-64,
• single-float, and
• double-float.

address must be an exact integer in the range $-2^{w-1}$ through $2^w - 1$, where $w$ is the width in bits of a pointer, e.g., 64 for a 64-bit machine. offset must be an exact fixnum. The sum of address and offset should address a readable block of memory large enough to hold a value of type type, within a block of storage previously returned by foreign-alloc and not subsequently freed by foreign-free or within a block of storage obtained via some
other mechanism, e.g., a foreign call. For multiple-byte values, the native endianness of the machine is assumed.

\[
\text{(foreign-set! type address offset value)}
\]

**procedure**

**returns:** see below

**libraries:** (chezscheme)

`foreign-set!` stores a representation of `value` as type `type` `offset` bytes into the block of foreign data addressed by `address`.

`type` must be a symbol identifying the type of value to be stored, one of those listed in the description of `foreign-ref` above. Scheme characters are converted to type `char` or `wchar_t` as if via `char->integer`. For type `boolean`, Scheme `#f` is converted to the `int` 0, and any other Scheme object is converted to 1.

`address` must be an exact integer in the range $-2^{w-1}$ through $2^w - 1$, where $w$ is the width in bits of a pointer, e.g., 64 for a 64-bit machine. `offset` must be an exact fixnum. The sum of `address` and `offset` should address a writable block of memory large enough to hold a value of type `type`, within a block of storage previously returned by `foreign-alloc` and not subsequently freed by `foreign-free` or within a block of storage obtained via some other mechanism, e.g., a foreign call. `value` must be an appropriate value for `type`, e.g., a floating-point number for the float types or an exact integer within the appropriate range for the integer types. For multiple-byte values, the native endianness of the machine is assumed.

\[
\text{(foreign-sizeof type)}
\]

**procedure**

**returns:** the size in bytes of `type`

**libraries:** (chezscheme)

`type` must be one of the symbols listed in the description of `foreign-ref` above.

\[
\text{(foreign-alignof type)}
\]

**procedure**

**returns:** the alignment in bytes of `type`

**libraries:** (chezscheme)

`type` must be one of the symbols listed in the description of `foreign-ref` above.

\[
\text{(define-ftype ftype-name ftype) (define-ftype (ftype-name ftype) ...)}
\]

**syntax**

**returns:** unspecified

**libraries:** (chezscheme)

A `define-ftype` form is a definition and can appear anywhere other definitions can appear. It establishes one or more foreign-type (ftype) bindings for the identifier `ftype-name` or identifiers `ftype-name` ... to the foreign type represented `ftype` or the foreign types represented by `ftype` ... . Each `ftype-name` can be used to access foreign objects with the declared shape, and each can be used in the formation of other ftypes.
An \textit{ftype} must take one of the following forms:

\begin{verbatim}
ftype-name
(struct (field-name ftype) ...)
(union (field-name ftype) ...)
(array length ftype)
(* ftype)
(bits (field-name signedness bits) ...)
(function conv ... (ftype ...) ftype)
(packed ftype)
(unpacked ftype)
(endian endianness ftype)
\end{verbatim}

where \textit{length} is an exact nonnegative integer, \textit{bits} is an exact positive integer, \textit{field-name} is an identifier, \textit{conv} is \#f or a string naming a valid convention as described on page 4.2, \textit{signedness} is either \texttt{signed} or \texttt{unsigned}, and \textit{endianness} is one of \texttt{native}, \texttt{swapped}, \texttt{big}, or \texttt{little}.

A restriction not reflected above is that \texttt{function} ftypes cannot be used as the types of field names or array elements. That is, function ftypes are valid only at the top level of an ftype, e.g.,

\begin{verbatim}
(define-ftype bvcopy_t (function (u8* u8* size_t) void))
\end{verbatim}

or as the immediate sub-type of a pointer (*) ftype, as in the following definitions, which are equivalent assuming the definition of \texttt{bvcopy_t} above.

\begin{verbatim}
(define-ftype A
  (struct
    [x int]
    [f (* (function (u8* u8* size_t) void))])))
\end{verbatim}

\begin{verbatim}
(define-ftype A
  (struct
    [x int]
    [f (* bvcopy_t)]))
\end{verbatim}

That is, a function cannot be embedded within a struct, union, or array, but a pointer to a function can be so embedded.

The following definitions establish ftype bindings for F, A, and E.

\begin{verbatim}
(define-ftype F (function (wchar_t int) int))
(define-ftype A (array 10 wchar_t))
\end{verbatim}

\begin{verbatim}
(define-ftype E
  (struct
    [a int]
    [b double]
    [c (array 25
      (struct
\end{verbatim}
The ftype $F$ describes the type of a foreign function that takes two arguments, a wide character and an integer, and returns an integer. The ftype $A$ is simply an array of 10 wchar_t values, and its size will be 10 times the size of a single wchar_t. The ftype $E$ is a structure with six fields: an integer $a$, a double-float $b$, an array $c$, a union $d$, a pointer $e$, and a pointer $f$. The array $c$ is an array of 25 structs, each of which contains a short integer, a long integer, and a $A$ array. The size of the $c$ array will be 25 times the size of a single $A$ array, plus 25 times the space needed to store each of the short and long integers.

The union $d$ is either a 32-bit unsigned integer or a 32-bit unsigned integer split into high (12 bits) and low (20 bits) components. The fields of a union overlap so that writing to one effectively overlaps the other. Thus, one can use the $d$ union type to split apart an unsigned integer by writing the integer into $v1$ and reading the pieces from $hi$ and $lo$. The pointer $e$ points to an $A$ array; it is not itself an array, and its size is just the size of a single pointer. Similarly, $f$ points to a function, and its size is also that of a single pointer.

An underscore (_ ) can be used as the field name for one or more fields of a struct, union, or bits ftype. Such fields are included in the layout but are considered unnamed and cannot be accessed via the ftype operators described below. Thus, in the example above, the long field within the $c$ array is inaccessible.

Non-underscore field names are handled symbolically, i.e., they are treated as symbols rather than identifiers. Each symbol must be unique (as a symbol) with respect to the other field names within a single struct, union, or bits ftype but need not be unique with respect to field names in other struct, union, or bits ftypes within the same ftype.

Each ftype-name in an ftype must either (a) have been defined previously by define-fetype, (b) be defined by the current define-fetype, or (c) be a base-type name, i.e., one of the type names supported by foreign-ref and foreign-set!. In case (b), any reference within one ftype to the ftype-name of one of the earlier bindings is permissible, but a reference to the ftype-name of the current or a subsequent binding can appear only within a pointer field.

For example, in:

(define-fetype
  [Qlist (struct
    [head int]
    [tail (* Qlist))])

the reference to Qlist is permissible since it appears within a pointer field. Similarly, in:
(define-fctype
  [Qfrob (struct
               [head int]
               [xtra Qfrob]
               [tail (* Qsnark)]])
  [Qsnark (struct
               [head int]
               [tail (* Qfrob)]))]

the mutually recursive references to Qsnark and Qfrob are permissible. In the following, however:

(define-fctype
  [Qfrob (struct
               [head int]
               [xtra Qfrob]
               [tail (* Qsnark)]))
  [Qsnark (struct
               [head int]
               [tail (* Qfrob)]))]

the reference to Qfrob within the ftype for Qfrob is invalid, and in:

(define-fctype
  [Qfrob (struct
               [head int]
               [xtra Qsnark]
               [tail (* Qsnark)]))
  [Qsnark (struct
               [head int]
               [tail (* Qfrob)]))]

the reference to Qsnark is similarly invalid.

By default, padding is inserted where appropriate to maintain proper alignment of multiple-byte scalar values in an attempt to mirror the target machine’s C struct layout conventions, where such layouts are adequately documented. For packed ftypes (ftypes wrapped in a packed form with no closer enclosing unpacked form), this padding is not inserted.

Multiple-byte scalar values are stored in memory using the target machine’s native “endian-ness,” e.g., little on X86 and X86_64-based platforms and big on Sparc-based platforms. Big-endian or little-endian representation can be forced via the endian ftype with a big or little endianness specifier. The native specifier can be used to force a return back to native representation. The swapped specifier can be used to swap the representation relative to the default or enclosing representation. Each endian form affects only ftypes nested syntactically within it and not nested within a closer endian form. The endianness of an ftype is fixed once it is defined.

The total size $n$ of the fields within an ftype bits form must be 8, 16, 24, 32, 40, 48, 56, or 64. Padding must be added manually, if needed. In little-endian representation, the first field occupies the low-order bits of the containing 8, 16, 24, 32, 40, 48, 56, or 64-bit word,
with each subsequent field just above the preceding field. In big-endian representation, the first field occupies the high-order bits, with each subsequent field just below the preceding field. For a machine type where endianness is not known at compile time (such as the portable bytecode virtual machine), a bit field must be specified explicitly as \texttt{big} or \texttt{little} endian by an enclosing declaration.

Two \texttt{ftype}s are considered equivalent only if defined by the same \texttt{ftype} binding. If two \texttt{ftype} definitions look identical but appear in two parts of the same program, the \texttt{ftype}s are not identical, and attempts to access one using the name of the other via the operators described below will fail with a run-time exception.

Array bounds must always be constant. If an array’s length cannot be known until run time, the array can be placed at the end of the \texttt{ftype} (and any containing \texttt{ftype}) and declared to have size zero, as illustrated by the example below.

\begin{verbatim}
(define-ftype Vec
  (struct
    [len int]
    [data (array 0 double)]))
(define make-Vec
  (lambda (n)
    (let ([fptr (make-ftype-pointer Vec
               (foreign-alloc
                 (+ (ftype-sizeof Vec)
                    (* (ftype-sizeof double) n))))])
      (ftype-set! Vec (len) fptr n)
      fptr)))
(define x (make-Vec 100))
(/ (- (ftype-pointer-address (ftype-&ref Vec (data 10) x))
     (ftype-pointer-address x))
  (ftype-sizeof int))
  ⇒ 10
(foreign-free (ftype-pointer-address x))
\end{verbatim}

No array bounds checks are performed for zero-length arrays. Only one variable-sized array can appear in a single foreign object, but one can work around this by treating the object as multiple individual objects.

To avoid specifying the constant length of an array in more than one place, a macro that binds both a variable to the size as well as an \texttt{ftype} name to the \texttt{ftype} can be used. For example,

\begin{verbatim}
(define-syntax define-array
  (syntax-rules ()
    [(_ array-name type size-name size)
      (begin
        (define size-name size)
        (define-ftype array-name
          (array size type)))])
(define-array A int A-size 100)
A-size ⇒ 100
\end{verbatim}
(ftype-pointer-ftype
  (make-ftype-pointer A
    (foreign-alloc (ftype-sizeof A)))) ⇒ (array 100 int)

This technique can be used to define arbitrary ftypes with arbitrary numbers of array fields. A struct ftype is an implicit subtype of the type of the first field of the struct. Similarly, an array ftype is an implicit subtype of the type of its elements. Thus, the struct or array extends the type of first field or element with additional fields or elements. This allows an instance of the struct or array to be treated as an instance of the type of its first field or element, without the need to use ftype-&ref to allocate a new pointer to the field or element.

(ftype-sizeof ftype-name)  
returns: the size in bytes of the ftype identified by ftype-name  
libraries: (chezscheme)

The size includes the sizes of any ftypes directly embedded within the identified ftype but excludes those indirectly embedded via a pointer ftype. In the latter case, the size of the pointer is included.

ftype-name must not be defined as a function ftype, since the size of a function cannot generally be determined.

(define-ftype B
  (struct
    [b1 integer-32]
    [b2 (array 10 integer-32)]))
(ftype-sizeof B) ⇒ 44

(define-ftype C (* B))
(ftype-sizeof C) ⇒ 4 ; on 32-bit machines
(ftype-sizeof C) ⇒ 8 ; on 64-bit machines

(define-ftype BB
 (struct
   [bb1 B]
   [bb2 (* B)]))
(- (ftype-sizeof BB) (ftype-sizeof void*)) ⇒ 44

(make-ftype-pointer ftype-name expr)  
returns: an ftype-pointer object  
libraries: (chezscheme)

If ftype-name does not describe a function ftype, expr must evaluate to an address represented as an exact integer in the appropriate range for the target machine.

The ftype-pointer object returned by this procedure encapsulates the address and is tagged with a representation of the type identified by ftype-name to enable various forms of checking to be done by the access routines described below.
4.5. Foreign Data

(make-ftype-pointer E #x80000000) ⇒ #<ftype-pointer #x80000000>

The address will not typically be a constant, as shown. Instead, it might instead come from a call to foreign-alloc, e.g.:

(make-ftype-pointer E (foreign-alloc (ftype-sizeof E)))

It might also come from source outside of Scheme such as from a C routine called from Scheme via the foreign-procedure interface.

If ftype-name describes a function ftype, expr must evaluate to an address, procedure, or string. If it evaluates to address, the call behaves like any other call to make-ftype-pointer with an address argument.

If it evaluates to a procedure, a foreign-callable code object is created for the procedure, as if via foreign-callable (Section §4.3). The address encapsulated in the resulting ftype-pointer object is the address of the procedure’s entry point.

(define fact
  (lambda (n)
    (if (= n 0) 1 (fact (- n 1)))))
(define-ftype fact_t (function (int) int))
(define fact-fptr (make-ftype-pointer fact_t fact))

The resulting ftype pointer can be passed to a C routine, if the argument is declared to be a pointer to the same ftype, and the C routine can invoke the function pointer it receives as it would any other function pointer. Thus, make-ftype-pointer with a function ftype is an alternative to foreign-callable for creating C-callable wrappers for Scheme procedures.

Since the foreign-callable code object can be reclaimed by the garbage collector if it is not otherwise referenced, the implicit foreign-callable’s code object is automatically locked, as if via lock-object, before it is embedded in the ftype pointer. The code object should be unlocked after its last use from C, since locked objects take up space, cause fragmentation, and increase the cost of collection. Since the system cannot determine automatically when the last use from C occurs, the program must explicitly unlock the code object, which it can do by extracting the address from the ftype-pointer converting the address (back) into a code object, and passing it to unlock-object:

(unlock-object
  (foreign-callable-code-object
   (ftype-pointer-address fact-fptr)))

Even after the code object is unlocked, the code object will remain immobile as long as a result of foreign-callable-code-object is retained. However, if only the ftype pointer object is retained, then the ftype pointer should not be used again unless it is relocked, e.g., via:

(lock-object
  (foreign-callable-code-object
   (ftype-pointer-address fact-fptr)))
A program can determine whether an object is already locked via the `locked-object?` predicate.

A function `ftype` can be also used with `make-ftype-pointer` to create an ftype-pointer to a C function, either by providing the address of the C function or its name, represented as a string. For example, with the following definition of `bvcopy_t`,

\[(\text{define-ftype } bvcopy\_t \ (\text{function } (u8\* \ u8\* \ size\_t) \ void))\]

the two definitions of `bvcopy-fptr` below are equivalent.

\[(\text{define } bvcopy\_fptr \ (\text{make-ftype-pointer } bvcopy\_t \ "memcpy") )\]
\[(\text{define } bvcopy\_fptr \ (\text{make-ftype-pointer } bvcopy\_t \ (\text{foreign-entry } "memcpy") )\]

A library that defines `memcpy` must be loaded first via `load-shared-object`, or `memcpy` must be registered via one of the methods described in Section 4.7.

\[(\text{ftype-pointer? } obj)\]
syntax
returns: #t if `obj` is an ftype pointer, otherwise #f

\[(\text{ftype-pointer? } \text{ftype-name} \ obj)\]
syntax
returns: #t if `obj` is an `ftype-name`, otherwise #f

libraries: (chezscheme)

\[(\text{define-ftype } \text{Widget1} \ (\text{struct } [x \ \text{int}] [y \ \text{int}]))\]
\[(\text{define-ftype } \text{Widget2} \ (\text{struct } [w \ \text{Widget1}] [b \ \text{boolean}]))\]

\[(\text{define } x1 \ (\text{make-ftype-pointer } \text{Widget1} \ #x80000000))\]
\[(\text{define } x2 \ (\text{make-ftype-pointer } \text{Widget2} \ #x80000000))\]

\[(\text{ftype-pointer? } x1) \Rightarrow \ #t\]
\[(\text{ftype-pointer? } x2) \Rightarrow \ #t\]

\[(\text{ftype-pointer? } \text{Widget1} \ x1) \Rightarrow \ #t\]
\[(\text{ftype-pointer? } \text{Widget1} \ x2) \Rightarrow \ #t\]

\[(\text{ftype-pointer? } \text{Widget2} \ x1) \Rightarrow \ #f\]
\[(\text{ftype-pointer? } \text{Widget2} \ x2) \Rightarrow \ #t\]

\[(\text{ftype-pointer? } #x80000000) \Rightarrow \ #f\]
\[(\text{ftype-pointer? } \text{Widget1} \ #x80000000) \Rightarrow \ #f\]

\[(\text{ftype-pointer-address } fptr)\]
procedure
returns: the address encapsulated within `fptr`
libraries: (chezscheme)

`fptr` must be an ftype-pointer object.

\[(\text{define } x \ (\text{make-ftype-pointer } E \ #x80000000))\]
\[(\text{ftype-pointer-address } x) \Rightarrow \ #x80000000\]
4.5. Foreign Data

\[
(f\text{-type-pointer=}? \ fptr_1 \ fptr_2)
\]

\textit{return:} \ #t \text{ if } fptr_1 \text{ and } fptr_2 \text{ have the same address, otherwise } #f

\textit{libraries:} (chezscheme)

\(fptr_1\) and \(fptr_2\) must be \textit{f}\textit{type-pointer} objects.

\textit{f}\textit{type-pointer=}? \texttt{might be defined as follows:}

\[
\begin{align*}
\text{(define ftype-pointer=}? \\
\text{(lambda (fptr1 fptr2) \\
\quad (= (ftype-pointer-address fptr1) (ftype-pointer-address fptr2))))}
\end{align*}
\]

It is, however, guaranteed not to allocate bignums for the addresses even if the addresses
do not fit in fixnum range.

\[
(f\text{-type-pointer-null?} \ fptr)
\]

\textit{return:} \ #t \text{ if the address of } fptr \text{ is 0, otherwise } #f

\textit{libraries:} (chezscheme)

\(fptr\) must be an \textit{f}\textit{type-pointer} object.

\textit{f}\textit{type-pointer-null?} \texttt{might be defined as follows:}

\[
\begin{align*}
\text{(define ftype-pointer-null?}
\quad \text{(lambda (fptr) \\
\quad \quad (= (ftype-pointer-address fptr) 0)))}
\end{align*}
\]

It is, however, guaranteed not to allocate a bignum for the address even if the address does
not fit in fixnum range.

\[
(f\text{-\&ref} \ ftype-name (a \ldots) fptr-expr)
\]

\[
(f\text{-\&ref} \ ftype-name (a \ldots) fptr-expr \ index)
\]

\textit{return:} an \textit{f}\textit{type-pointer} object

\textit{libraries:} (chezscheme)

The \textit{f}\textit{type-pointer} object returned by \textit{f}\textit{type-\&ref} \text{encapsulates the address of some object}
embedded directly or indirectly within the foreign object pointed to by the value of
\textit{fptr-expr}, offset by \textit{index}, if present. The value of \textit{fptr-expr} must be an \textit{f}\textit{type pointer} (\textit{fptr})
of the \textit{f}\textit{type} identified by \textit{f}\textit{type-name}, and \textit{index} must either be the identifier \texttt{*} or evaluate
to a fixnum, possibly negative. The index is automatically scaled by the size of the \textit{f}\textit{type}
identified by \textit{f}\textit{type-name}, which allows the \textit{fptr} to be treated as an array of \textit{f}\textit{type-name}
objects and \textit{index} as an index into that array. An index of \texttt{*} or \texttt{0} is the same as no index.

The sequence of accessors \texttt{a} \ldots \texttt{must specify a valid path through the identified \textit{f}\textit{type}. For
\texttt{struct}, \texttt{union}, and \texttt{bits} \textit{f}\textit{types}, an accessor must be a valid field name for the \textit{f}\textit{type}, while
for \textit{pointer} and \textit{array} \textit{f}\textit{types}, an accessor must be the identifier \texttt{*} or evaluate to a fixnum
index. For \textit{array} \textit{f}\textit{types}, an index must be nonnegative, and for \textit{array} \textit{f}\textit{types} with nonzero
length, an index must also be less than the length.
The examples below assume the definitions of \( B \) and \( BB \) shown above in the description of \texttt{ftype-sizeof}. Fixed addresses are shown for illustrative purposes and are assumed to be valid, although addresses are generally determined at run time via \texttt{foreign-alloc} or some other mechanism.

\begin{verbatim}
(define x (make-ftype-pointer B #x80000000))
(ftype-&ref B () x) ⇒ #<ftype-pointer #x80000000>
(let ([idx 1]) ⇒ #<ftype-pointer #x80000002C>
 (ftype-&ref B () x idx))
(let ([idx -1]) ⇒ #<ftype-pointer #x7FFFFFDD4>
 (ftype-&ref B (b1) x))
(ftype-&ref B (b1 b2) x) ⇒ #<ftype-pointer #x80000004>
(ftype-&ref B (b2 5) x) ⇒ #<ftype-pointer #x80000018>
(let ([n 5]) (ftype-&ref B (b2 n) x)) ⇒ #<ftype-pointer #x80000018>

(define y (make-ftype-pointer BB #x90000000))
(ftype-set! BB (bb2) y x)
(ftype-&ref BB (bb1 b2) y) ⇒ #<ftype-pointer #x90000004>
(ftype-&ref BB (bb2 * b2) y) ⇒ #<ftype-pointer #x80000004>
(let ([idx 1]) ⇒ #<ftype-pointer #x80000030>
 (ftype-&ref BB (bb2 idx b2) y))
\end{verbatim}

With no accessors and no index, as in the first use of \texttt{ftype-&ref} above, the returned \texttt{ftype-pointer} might be \texttt{eq?} to the input. Otherwise, the \texttt{ftype-pointer} is freshly allocated.

\begin{verbatim}
(ftype-set! ftype-name (a ...) fpstr-expr val-expr) syntax
(ftype-set! ftype-name (a ...) fpstr-expr index val-expr) syntax
returns: unspecified

(ftype-ref ftype-name (a ...) fpstr-expr) syntax
(ftype-ref ftype-name (a ...) fpstr-expr index) syntax
returns: an ftype-pointer object
libraries: (chezscheme)
\end{verbatim}

These forms are used to store values into or retrieve values from the object pointed to by the value of \texttt{fpstr-expr}, offset by \texttt{index}, if present. The value of \texttt{fpstr-expr} must be an ftype pointer (fptr) of the ftype identified by \texttt{ftype-name}, and \texttt{index} must either be the identifier \* or evaluate to a fixnum, possibly negative. The index is automatically scaled by the size of the ftype identified by \texttt{ftype-name}, which allows the fptr to be treated as an array of \texttt{ftype-name} objects and \texttt{index} as an index into that array. An index of \* or 0 is the same as no index.

The sequence of accessors \texttt{a ...} must specify a valid path through the identified ftype. For \texttt{struct}, \texttt{union}, and \texttt{bits} ftypes, an accessor must be a valid field name for the ftype, while for pointer and array ftypes, an accessor must be the identifier \* or evaluate to a fixnum
index. For array ftypes, an index must be nonnegative, and for array ftypes with nonzero length, an index must also be less than the length. The field or element specified by the sequence of accessors must be a scalar field, e.g., a pointer field or a field containing a base type such as an int, char, or double.

For ftype-set!, val-expr must evaluate to a value of the appropriate type for the specified field, e.g., an ftype pointer of the appropriate type or an appropriate base-type value.

For both signed and unsigned integer fields, values in the range $-2^{w-1}$ through $2^w - 1$ are accepted, where $w$ is the width in bits of the integer field. For signed integer fields, values in the range $2^w - 1$ through $2^{w+1}$ are treated as two’s complement representations of the corresponding negative numbers. For unsigned integer fields, values in the range $-2^{w-1}$ through $-1$ are similarly treated as two’s complement representations of the corresponding positive numbers.

char and wchar_t (wchar) field values are converted from (ftype-set!) or to (ftype-ref) Scheme characters, as if with char->integer and integer->char. Characters stored by ftype-set! into a char field must have Unicode scalar values in the range 0 through 255. Under Windows and any other system where wchar_t (wchar) is a 16-bit value, characters stored by ftype-set! into a wchar_t (wchar) field must have Unicode scalar values in the range 0 through $2^{16} - 1$. On systems where wchar_t is a 32-bit value, any character can be stored in a wchar_t (wchar) field.

The examples below assume that B and C have been defined as shown in the description of ftype-sizeof above.

(define b
  (make-ftype-pointer B
    (foreign-alloc
      (* (ftype-sizeof B) 3))))
(define c
  (make-ftype-pointer C
    (foreign-alloc (ftype-sizeof C))))

(ftype-set! B (b1) b 5)
(ftype-set! B (b1) b 1 6)
(ftype-set! B (b1) c 5)  ⇒  exception: ftype mismatch
(ftype-set! B (b2) b 0)  ⇒  exception: not a scalar
(ftype-set! B (b2 -1) b 0)  ⇒  exception: invalid index
(ftype-set! B (b2 0) b 50)
(ftype-set! B (b2 4) b 55)
(ftype-set! B (b2 10) b 55)  ⇒  exception: invalid index

(ftype-set! C () c (ftype-&ref B () b 1))

(= (ftype-pointer-address (ftype-ref C () c))  ⇒  #t
    (+ (ftype-pointer-address b) (ftype-sizeof B)))
(= (ftype-pointer-address (ftype-&ref C (*) c))  ⇒  #t
    (+ (ftype-pointer-address b) (ftype-sizeof B)))
(= (ftype-pointer-address (ftype-&ref C (-1) c))  ⇒  #t
    (ftype-pointer-address b))
A function ftype pointer can be converted into a Scheme-callable procedure via ftype-ref. Assuming that a library defining memcpy has been loaded via load-shared-object or memcpy has been registered via one of the methods described in Section 4.7, a Scheme-callable memcpy can be defined as follows.

```
(define-ftype bvcopy_t (function (u8* u8* size_t) void))
(define bvcopy-fptr (make-ftype-pointer bvcopy_t "memcpy"))
(define bvcopy (ftype-ref bvcopy_t () bvcopy-fptr))

(define bv1 (make-bytevector 8 0))
(define bv2 (make-bytevector 8 57))
(bvcopy bv1 bv2 5)
```

An ftype pointer can also be obtained as a return value from a C function declared to return a pointer to a function ftype. Thus, ftype-ref with a function ftype is an alternative to foreign-procedure (Section 4.2) for creating Scheme-callable wrappers for C functions.

```
(fctype-pointer-fctype fptr)
```

**returns:** fptr's ftype, represented as an s-expression

**libraries:** (chezscheme)

fptr must be an ftype-pointer object.

```
(define-ftype Q0
  (struct
    [x int]
    [y int]))
(define-ftype Q1
  (struct
    [x double]
    [y char]
    [z (endian big
      (bits
        [_ unsigned 3]
        [a unsigned 9]
        [b unsigned 41)])))]
```
4.5. Foreign Data

(define q1 (make-ftype-pointer Q1 0))
(fctype-pointer-fctype q1) ⇒ (struct
  [x double]
  [y char]
  [z (Endian big
       (bits
         [z unsigned 3]
         [a unsigned 9]
         [b unsigned 4])])
  [w (* Q0)])

(fctype-pointer->sexpr fptr) procedure
returns: an s-expression representation of the object to which fptr points
libraries: (chezscheme)

fptr must be an ftype-pointer object.
For each unnamed field, i.e., each whose field name is an underscore, the corresponding field value in the resulting s-expression is also an underscore. Similarly, if a field is inaccessible, i.e., if its address is invalid, the value is the symbol invalid.

(define-fctype Frob
  (struct
    [p boolean]
    [q char]))
(define-fctype Snurk
  (struct
    [a Frob]
    [b (* Frob)]
    [c (* Frob)]
    [d (bits
        [z unsigned 15]
        [dx signed 17]])
    [e (array 5 double)]))
(define x
  (make-fctype-pointer Snurk
    (foreign-alloc (fctype-sizeof Snurk))))
(fctype-set! Snurk (b) x
  (make-fctype-pointer Frob
    (foreign-alloc (fctype-sizeof Frob)))))
(fctype-set! Snurk (c) x
  (make-fctype-pointer Frob 0))
(fctype-set! Snurk (a p) x #t)
(fctype-set! Snurk (a q) x #\A)
(fctype-set! Snurk (b * p) x #f)
(fctype-set! Snurk (b * q) x #\B)
(fctype-set! Snurk (d dx) x -2500)
(do ([i 0 (fx+ i 1)])
  ((fx= i 5)))
(ftype-set! Snurk (e i) x (+ (* i 5.0) 3.0)))
(ftype-pointer->sexpr x) ⇒ (struct
  [a (struct [p #t] [q #\A])]
  [b (* (struct [p #f] [q #\B]))]
  [c (* (struct [p invalid] [q invalid]))]
  [d (bits [_._] [dx -2500])]
  [e (array 5 3.0 8.0 13.0 18.0 23.0)])

4.6. Foreign Arrays of Managed Objects

When a bytevector value is passed in a foreign call as an argument of type u8*, the foreign procedure receives a pointer to the start of the bytevector’s content. The function object->reference-address returns that same address, but it is valid only if the bytevector does not move. If the storage manager later moves the bytevector in memory, then the address becomes invalid. The bytevector can be locked with lock-object to prevent the storage manager from relocating it, so that the content address will remain valid, but then it must be explicitly unlocked later with unlock-object.

Having to explicitly lock and unlock objects can make interoperating with foreign procedures difficult when the foreign procedure expects an array of references (for example, as a char** argument). It may seem that a vector of bytevectors could serve that purpose, but although a Scheme vector is an array of references at some level, a vector’s reference to a bytevector does not point to the start of the bytevector’s content.

A reference bytevector is a type of bytevector that can be used to solve this problem by storing the addresses of the contents of scheme objects using bytevector-reference-set!. Reference bytevectors are recognized and treated specially by the storage manager, so that the addresses contained in the reference byte vector are both recognized as a reference to a scheme object and updated appropriately if the storage manager moves that object. A reference bytevector can refer to any type of Scheme object, but the meaning of the address is specified for only three kinds of object: The address for bytevectors and flvectors is the pointer to their content, and the address for #f is 0. In addition, a reference bytevector can contain foreign addresses, which are addresses of memory outside of the storage manager’s ranges, but beware that an address range released by a foreign allocator might later become a range that belongs to the Scheme storage manager. During the time that a garbage collection is possible (i.e., when interrupts have not been disabled), every aligned word (i.e. (ftype-sizeof uptr)) in a reference bytevector must hold a valid object reference or a foreign address.

While all of the procedures described in this section support unaligned access (for consistency with other bytevector operations), use extreme caution when using any byte offset other than an even multiple of the current machine’s pointer size (i.e., (ftype-sizeof uptr)). Some procedures note cases in which behavior is undefined. Undefined behavior may include invalid memory references, corrupted data, or system crashes.
4.6. Foreign Arrays of Managed Objects

(make-reference-bytevector n)
returns: a reference bytevector of length n
libraries: (chezscheme)

Like make-bytevector, but the result is a reference bytevector that is initialized with all
bytes being 0 (i.e., all referenced objects being #f and any trailing bytes after an even
multiple of the current machine’s pointer size being 0).

(make-immobile-reference-bytevector n)
returns: a reference bytevector of length n
libraries: (chezscheme)

Like make-reference-bytevector, but creates a reference bytevector that will not be relo-
cated in memory by the storage management system until it is reclaimed.

(reference-bytevector? obj)
returns: #t if obj is an reference bytevector, #f otherwise
libraries: (chezscheme)

Note that every reference bytevector is also a bytevector that is recognized by bytevector?,
and equal? considers two bytevectors independent of whether either is a reference bytevec-
tor.

(bytevector-reference-set! bytevector n obj)
returns: unspecified
libraries: (chezscheme)

bytevector must be a reference bytevector, and n must be a nonnegative fixnum. The sum
of n and the size of a pointer (i.e., (ftype-sizeof uptr)) must not be greater than the
length of bytevector.

Installs a reference to obj at byte offset n within bytevector. In the case that obj is a
bytevector or flvector, the reference is represented as the starting address of the bytevector
or flvector’s content. If obj is #f then the reference is represented as 0. The reference
occupies (ftype-sizeof uptr) bytes.

(bytevector-reference-ref bytevector n)
returns: a Scheme object
libraries: (chezscheme)

bytevector must be a reference bytevector, and n must be a nonnegative fixnum. The sum
of n and the size of a pointer (i.e., (ftype-sizeof uptr)) must not be greater than the
length of bytevector.

Returns the object that is referenced in bytevector at byte offset n. If the (ftype-sizeof uptr)
bytes at offset n do not represent a reference to a valid Scheme object then behavior is
undefined.
(bytevector-reference*-ref bytevector n) procedure
returns: an allocated Scheme object or a positive exact integer
libraries: (chezscheme)

Like bytevector-reference-ref, but if bytevector at byte offset n holds a non-0 foreign
address, bytevector-reference*-ref returns an integer. The representation of a refer-
ence to a Scheme object can overlap with the representation of a foreign address; see
reference*-address->object.

(object->reference-address obj) procedure
returns: a nonnegative exact integer
libraries: (chezscheme)

The result is 0 if obj is #f, and it is the address of objs’s content in the case that obj
is a bytevector or flvector—at least, at the point where object->reference-address was
called. Unless obj is a locked or immobile bytevector or flvector, its address can change at
any time that a garbage collection is possible (i.e., when interrupts are enabled). For other
kinds of objs, the representation of the returned address is not specified, except that it is
a nonnegative exact integer that is distinct from any other object’s representation.

(reference-address->object addr) procedure
returns: a Scheme object
libraries: (chezscheme)

addr must be a nonnegative exact integer that is a valid reference to a Scheme object, and
the result is the referenced Scheme object. If addr is not a valid reference to a Scheme
object then behavior is undefined.

(reference*-address->object addr) procedure
returns: a Scheme object, possibly addr itself
libraries: (chezscheme)

addr must be a nonnegative exact integer that is a valid reference to a Scheme object, or it
must be an foreign address that is outside the range that belongs to the storage manager.
When addr is 0, the result is #f. Otherwise, if addr is a foreign address, then addr itself is
returned.

The representation of a reference to a bytevector or flvector is guaranteed to be distinct
from any foreign address, but other values may have a representation that overlaps with
foreign addresses, in which case addr is returned (i.e., the foreign-address interpretation
takes precedence). Thus, reference*-address->object and bytevector-reference*-ref
are mainly useful for an address that is known to be either a bytevector reference, an
flvector reference, or a foreign address.

If addr is not a foreign address and does not reference a valid Scheme object then behavior
is undefined.
4.7. Providing Access to Foreign Procedures

Access to foreign procedures can be provided in several ways:

- **Foreign procedures may be loaded from “shared objects”** using `load-shared-object`.
- **A new Chez Scheme image can be built with additional foreign code linked in.** (Consult with the person who installed Chez Scheme at your site for details.) These entries are typically registered via `Sforeign_symbol` or `Sregister_symbol`, documented in Section [4.9].
- **Additional entries may be dynamically loaded or otherwise obtained by foreign code.** These are also typically registered using `Sforeign_symbol` or `Sregister_symbol`.
- **The address of an entry, i.e., a function pointer, may be passed into Scheme and used as the value of the entry expression in a foreign-procedure expression.** This allows foreign entry points to be used even when they are not registered by name.

```scheme
(foreign-entry? entry-name) procedure
returns: #t if entry-name is an existing foreign procedure entry point, #f otherwise
libraries: (chezscheme)

entry-name must be a string. foreign-entry? may be used to determine if an entry exists for a foreign procedure.

The following examples assume that a library that defines `strlen` has been loaded via `load-shared-object` or that `strlen` has been registered via one of the other methods described in this section.

```
(foreign-entry? "strlen") ⇒ #t
((foreign-procedure "strlen"
   (string) size_t)
  "hey!") ⇒ 4
```

```scheme
(foreign-entry entry-name) procedure
returns: the address of entry-name as an exact integer
libraries: (chezscheme)

entry-name must be a string naming an existing foreign entry point.

The following examples assume that a library that defines `strlen` has been loaded via `load-shared-object` or that `strlen` has been registered via one of the other methods described in this section.

```
(let ([addr (foreign-entry "strlen")])
  (and (integer? addr) (exact? addr))) ⇒ #t
```
(define-ftype strlen-type (function (string) size_t))
(define strlen
  (ftype-ref strlen-type ()
    (make-ftype-pointer strlen-type "strlen")))
(strlen "hey!") ⇒ 4

(foreign-address-name address) procedure
returns: the entry name corresponding to address, if known, otherwise #f
libraries: (chezscheme)

The following examples assume that a library that defines strlen has been loaded via load-shared-object or that strlen has been registered via one of the other methods described in this section.

(foreign-address-name (foreign-entry "strlen")) ⇒ "strlen"

(load-shared-object path) procedure
returns: unspecified
libraries: (chezscheme)

path must be a string. load-shared-object loads the shared object named by path. Shared objects may be system libraries or files created from ordinary C programs. All external symbols in the shared object, along with external symbols available in other shared objects linked with the shared object, are made available as foreign entries.

This procedure is supported for most platforms upon which Chez Scheme runs.

If path does not begin with a “.” or “/”, the shared object is searched for in a default set of directories determined by the system.

On most Unix systems, load-shared-object is based on the system routine dlopen. Under Windows, load-shared-object is based on LoadLibrary. Refer to the documentation for these routines and for the C compiler and loader for precise rules for locating and building shared objects.

load-shared-object can be used to access built-in C library functions, such as getenv. The name of the shared object varies from one system to another. On Linux systems:

(load-shared-object "libc.so.6")

On Solaris, OpenSolaris, FreeBSD, NetBSD, and OpenBSD systems:

(load-shared-object "libc.so")

On MacOS X systems:

(load-shared-object "libc.dylib")

On Windows:
Once the C library has been loaded, `getenv` should be available as a foreign entry.

An equivalent Scheme procedure may be defined and invoked as follows.

```scheme
(define getenv
  (foreign-procedure "getenv"
    (string)
    string))

(getenv "HOME")  ⇒  "/home/elmer/fudd"
(getenv "home")  ⇒  #f
```

`load-shared-object` can be used to access user-created libraries as well. Suppose the C file "even.c" contains

```c
int even(n) int n; { return n == 0 || odd(n - 1); }
```

and the C file "odd.c" contains

```c
int odd(n) int n; { return n != 0 && even(n - 1); }
```

The files must be compiled and linked into a shared object before they can be loaded. How this is done depends upon the host system. On Linux, FreeBSD, OpenBSD, and OpenSolaris systems:

```bash
(system "cc -fPIC -shared -o evenodd.so even.c odd.c")
```

Depending on the host configuration, the `-m32` or `-m64` option might be needed to specify 32-bit or 64-bit compilation as appropriate.

On MacOS X (Intel or PowerPC) systems:

```bash
(system "cc -dynamiclib -o evenodd.so even.c odd.c")
```

Depending on the host configuration, the `-m32` or `-m64` option might be needed to specify 32-bit or 64-bit compilation as appropriate.

On 32-bit Sparc Solaris:

```bash
(system "cc -KPIC -G -o evenodd.so even.c odd.c")
```

On 64-bit Sparc Solaris:

```bash
(system "cc -xarch=v9 -KPIC -G -o evenodd.so even.c odd.c")
```

On Windows, we build a DLL (dynamic link library) file. In order to make the compiler generate the appropriate entry points, we alter `even.c` to read

```c
#ifdef WIN32
#define EXPORT extern __declspec (dllexport)
#endif
```

```c
int even(n) int n; { return n == 0 || odd(n - 1); }
```
4. Foreign Interface

```c
#else
#define EXPORT extern
#endif

EXPORT int even(n) int n; { return n == 0 || odd(n - 1); }

and odd.c to read

#ifdef WIN32
#define EXPORT extern __declspec (dllexport)
#else
#define EXPORT extern
#endif

EXPORT int odd(n) int n; { return n != 0 && even(n - 1); }

We can then build the DLL as follows, giving it the extension “.so” rather than “.dll” for consistency with the other systems.

(system "cl -c -DWIN32 even.c")
(system "cl -c -DWIN32 odd.c")
(system "link -dll -out:evenodd.so even.obj odd.obj")

The resulting “.so” file can be loaded into Scheme and even and odd made available as foreign procedures:

(load-shared-object "/evenodd.so")
(let ([odd (foreign-procedure "odd"
               (integer-32) boolean)]
      [even (foreign-procedure "even"
               (integer-32) boolean)])
  (list (even 100) (odd 100))) ⇒ (#t #f)

The filename is given as "/evenodd.so" rather than simply "evenodd.so", because some systems look for shared libraries in a standard set of system directories that does not include the current directory.

(rem

(remove-foreign-entry entry-name) procedure
returns: unspecified
libraries: (chezscheme)

remove-foreign-entry blocks further access to the entry specified by the string entry-name. An exception is raised with condition type &assertion if the entry does not exist. Since access previously established by foreign-procedure is not affected, remove-foreign-entry may be used to clean up after the desired interface to a group of foreign procedures has been established.

remove-foreign-entry can be used to remove entries registered using Sforeign_symbol and Sregister_symbol but not entries created as a result of a call to load-shared-object.
4.8. Using Other Foreign Languages

Although the Chez Scheme foreign procedure interface is oriented primarily toward procedures defined in C or available in C libraries, it is possible to invoke procedures defined in other languages that follow C calling conventions. One source of difficulty may be the interpretation of names. Since Unix-based C compilers often prepend an underscore to external names, the foreign interface attempts to interpret entry names in a manner consistent with the host C compiler. Occasionally, such as for assembly coded files, this entry name interpretation may not be desired. It can be prevented by prefixing the entry name with an “=” character. For example, after loading an assembly file containing a procedure "foo" one might have:

(foreign-entry? "foo") ⇒ #f
(foreign-entry? "=foo") ⇒ #t

4.9. C Library Routines

Additional foreign interface support is provided via a set of C preprocessor macros and C-callable library functions. Some of these routines allow C programs to examine, allocate, and alter Scheme objects. Others permit C functions to call Scheme procedures via a more primitive interface than that defined in Section 4.3. Still others permit the development of custom executable images and use of the Scheme system as a subordinate program within another program, e.g., for use as an extension language.

C code that uses these routines must include the "scheme.h" header file distributed with Chez Scheme and must be linked (statically or dynamically) with the Chez Scheme kernel. The header file contains definitions for the preprocessor macros and extern declarations for the library functions. The file is customized to the release of Chez Scheme and machine type with which it is distributed; it should be left unmodified to facilitate switching among Chez Scheme releases, and the proper version of the header file should always be used with C code compiled for use with a particular version of Chez Scheme. The version and machine type are defined in "scheme.h" under the names VERSION and MACHINE_TYPE.

The name of each routine begins with a capital S, e.g., Sfixnump. Many of the names are simple translations of the names of closely related Scheme procedures, e.g., Sstring_to_symbol is the C interface equivalent of string->symbol. Most externally visible entries in the Chez Scheme executable that are not documented here begin with capital S followed by an underscore (S_); their use should be avoided.

In addition to the various macros and external declarations given in scheme.h, the header file also defines (typedefs) several types used in the header file:

- ptr: type of a Scheme value,
- iptr: a signed integer the same size as a Scheme value, and
- uptr: an unsigned integer the same size as a Scheme value.
- string_char: type of a single Scheme string element.
• **octet**: type of a single Scheme bytevector element (unsigned char).

These types may vary depending upon the platform, although `ptr` is typically `void *`, `iptr` is typically `long int`, and `uptr` is typically `unsigned long int`.

Under Windows, defining `SCHEME_IMPORT` before including `scheme.h` causes `scheme.h` to declare its entry points using `externdeclspec (dllimport)` rather than `externdeclspec (dllexport)` (the default). Not defining `SCHEME_IMPORT` and instead defining `SCHEME_STATIC` causes `scheme.h` to declare exports using just `extern`. The static libraries distributed with Chez Scheme are built using `SCHEME_STATIC`.

The remainder of this section describes each of the C interface routines in turn. A declaration for each routine is given in ANSI C function prototype notation to precisely specify the argument and result types. Scheme objects have the C type `ptr`, which is defined in "scheme.h". Where appropriate, C values are accepted as arguments or returned as values in place of Scheme objects.

The preprocessor macros may evaluate their arguments more than once (or not at all), so care should be taken to ensure that this does not cause problems.

**Customization.** The functions described here are used to initialize the Scheme system, build the Scheme heap, and run the Scheme system from a separate program.

```c
[func] char * Skernel_version(void)
[func] void Sscheme_init(void (*abnormal_exit)(void))
[func] void Sset_verbose(int v)
[func] void Sregister_boot_file(const char *name)
[func] void Sregister_boot_file_fd(const char *name, int fd)
[func] void Sregister_boot_file_fd_segment(const char *name, int fd, iptr offset, iptr len, int close_after)
[func] void Sbuild_heap(const char *exec, void (*custom_init)(void))
[func] void Senable_expeditor(const char *history_file)
[func] void Sretain_static_relocation(void)
[func] int Sscheme_start(int argc, char *argv[])
[func] int Sscheme_script(char *scriptfile, int argc, char *argv[])
[func] int Sscheme_program(char *programfile, int argc, char *argv[])
[func] void Scompact_heap(void)
[func] void Sscheme_deinit(void)
```

`Skernel_version` returns a string representing the Scheme version. It should be compared against the value of the VERSION preprocessor macro before any of the initialization functions listed above are used to verify that the correct "scheme.h" header file has been used.

`Sscheme_init` causes the Scheme system to initialize its static memory in preparation for boot file registration. The `abnormal_exit` parameter should be a (possibly null) pointer to a C function of no arguments that takes appropriate action if the initialization or subsequent heap-building process fails. If null, the default action is to call `exit(1)`.
**Sset_verbose** sets verbose mode on for nonzero values of \( v \) and off when \( v \) is zero. In verbose mode, the system displays a trace of the search process for subsequently registered boot files.

**Sregister_boot_file** searches for the named boot file and register it for loading, while **Sregister_boot_file_fd** provides a specific boot file as a file descriptor. When only a boot file name is provided, the file is opened but not loaded until the heap is built via **Sbuild_heap**. When a file descriptor is provided, the given file name is used only for error reporting. For the first boot file registered only, the system also searches for the boot files upon which the named file depends, either directly or indirectly.

The **Sregister_boot_file_fd_region** function is an alternative to **Sregister_boot_file_fd** that allows the same file descriptor to be used for multiple boot files using different offsets into the file. The \( \text{len} \) argument is used as a hint, but it can be 0 to mean that the size is unknown, or it can be larger than the actual boot content; it must not be non-0 and smaller than the boot content, and the boot content must be self-terminating independent of \( \text{len} \). No search is performed for dependencies. If the same file descriptor is used for multiple boot files, then **close_after** should be non-zero only for the last one. The boot file content is read only when **Sbuild_heap** is called.

**Sbuild_heap** creates the Scheme heap from the registered boot files. **exec** is assumed to be the name of or path to the executable image and is used when no boot files have been registered as the base name for the boot-file search process. **exec** may be null only if one or more boot files have been registered. **custom_init** must be a (possibly null) pointer to a C function of no arguments; if non-null, it is called before any boot files are loaded.

**SScheme_start** invokes the interactive startup procedure, i.e., the value of the parameter **scheme-start**, with one Scheme string argument for the first \( \text{argc} \) elements of \( \text{argv} \), not including \( \text{argv}[0] \). **SScheme_script** similarly invokes the script startup procedure, i.e., the value of the parameter **scheme-script**, with one Scheme string argument for **scriptfile** and the first \( \text{argc} \) elements of **argv**, not including \( \text{argv}[0] \). **SScheme_program** similarly invokes the program startup procedure, i.e., the value of the parameter **scheme-program**, with one Scheme string argument for **programfile** and the first \( \text{argc} \) elements of **argv**, not including \( \text{argv}[0] \).

**Senable_expeditor** enables the expression editor (Section 2.2, Chapter 14), which is disabled by default, and determines the history file from which it restores and to which it saves the history. This procedure must be called after the heap is built, or an error will result. It must also be called before **SScheme_start** in order to be effective. If the **history_file** argument is the null pointer, the history is not restored or saved. The preprocessor variable **FEATURE_EXPEDITOR** is defined in **scheme.h** if support for the expression editor has been compiled into the system.

**Sretain_static_relocation** causes relocation information to be retained for static generation code objects created by heap compaction for the benefit of **compute-size** and related procedures.

**Scompact_heap** compacts the Scheme heap and places all objects currently in the heap into a **static** generation. Objects in the static generation are never collected. That is, they are never moved during collection and the storage used for them is never reclaimed even if
they become inaccessible. \texttt{Scompact_heap} is called implicitly after any boot files have been loaded.

\texttt{Sscheme_deinit} closes any open files, tears down the Scheme heap, and puts the Scheme system in an uninitialized state.

\textbf{Predicates.} The predicates described here correspond to the similarly named Scheme predicates. A trailing letter \texttt{p}, for “predicate,” is used in place of the question mark that customarily appears at the end of a Scheme predicate name. Each predicate accepts a single Scheme object and returns a boolean (C integer) value.

\begin{verbatim}
[macro] int Sfixnump(ptr obj)
[macro] int Scharp(ptr obj)
[macro] int Snullp(ptr obj)
[macro] int Seof_objectp(ptr obj)
[macro] int Sbwp_objectp(ptr obj)
[macro] int Sbooleanp(ptr obj)
[macro] int Spairp(ptr obj)
[macro] int Ssymbolp(ptr obj)
[macro] int Sprocedurep(ptr obj)
[macro] int Sflonump(ptr obj)
[macro] int Svectorp(ptr obj)
[macro] int Sbytevectorp(ptr obj)
[macro] int Sstringp(ptr obj)
[macro] int Sbignump(ptr obj)
[macro] int Sboxp(ptr obj)
[macro] int Sinexactnump(ptr obj)
[macro] int Sexactnump(ptr obj)
[macro] int Sratnump(ptr obj)
[macro] int Sinputportp(ptr obj)
[macro] int Soutputportp(ptr obj)
[macro] int Srecordp(ptr obj)

\end{verbatim}

\textbf{Accessors.} Some of the accessors described here correspond to similarly named Scheme procedures, while others are unique to this interface. \texttt{Sfixnum_value}, \texttt{Schar_value}, \texttt{Sboolean_value}, and \texttt{Sflonum_value} return the C equivalents of the given Scheme value.

\begin{verbatim}
[macro] iptr Sfixnum_value(ptr fixnum)
[macro] uptr Schar_value(ptr character)
[macro] int Sboolean_value(ptr obj)
[macro] double Sflonum_value(ptr flonum)

\end{verbatim}

\texttt{Sinteger_value} and \texttt{Sunsigned_value} are similar to \texttt{Sfixnum_value}, except they accept not only fixnum arguments but bignum arguments in the range of C integer or unsigned values. \texttt{Sinteger_value} and \texttt{Sunsigned_value} accept the same range of Scheme integer values. They differ only in the result type, and so allow differing interpretations of negative and large unsigned values.
4.9. C Library Routines

[func] iptr Sinteger_value(ptr integer)
[macro] uptr Sunsigned_value(ptr integer)

Sinteger32_value, Sunsigned32_value, Sinteger64_value, and Sunsigned64_value accept signed or unsigned Scheme integers in the 32- or 64-bit range and return integers of the appropriate type for the machine type.

[func] Sint32_t Sinteger32_value(ptr integer)
[macro] Sunint32_t Sunsigned32_value(ptr integer)
[func] Sint64_t Sinteger64_value(ptr integer)
[macro] Sunint64_t Sunsigned64_value(ptr integer)

The functions Stry_integer_value, Stry_integer32_value, and Stry_integer64_value also convert Scheme values to C integers. Unlike the corresponding Sinteger_value functions, these functions do not raise exceptions. Instead, they take additional result and reason arguments and return 1 or 0 to indicate success or failure. If integer can be converted to the requested type, these functions store the value in result and return 1. Otherwise, they return 0 without modifying result. If integer cannot be converted to the requested type and reason is not NULL, these functions store a Scheme-style format string in reason explaining why the conversion failed. The corresponding functions for unsigned values are Stry_unsigned_value, Stry_unsigned32_value, and Stry_unsigned64_value.

[func] int Stry_integer_value(ptr integer, iptr* result, const char** reason)
[func] int Stry_integer32_value(ptr integer, Sint32_t* result, const char** reason)
[func] int Stry_integer64_value(ptr integer, Sint64_t* result, const char** reason)
[func] int Stry_unsigned_value(ptr integer, uptr* result, const char** reason)
[func] int Stry_unsigned32_value(ptr integer, Sunint32_t* result, const char** reason)
[func] int Stry_unsigned64_value(ptr integer, Sunint64_t* result, const char** reason)

Scar, Scdr, Ssymbol_to_string (corresponding to symbol->string), and Sunbox are identical to their Scheme counterparts.

[macro] ptr Scar(ptr pair)
[macro] ptr Scdr(ptr pair)
[func] ptr Ssymbol_to_string(ptr sym)
[macro] ptr Sunbox(ptr box)

Sstring_length, Svector_length, Sbytevector_length, and Sfxvector_length each return a C integer representing the length (in elements) of the object.

[macro] iptr Sstring_length(ptr str)
[macro] iptr Svector_length(ptr vec)
[macro] iptr Sbytevector_length(ptr bytevec)
[macro] iptr Sfxvector_length(ptr fxvec)

Sstring_ref, Svector_ref, Sbytevector_u8_ref, and Sfxvector_ref correspond to their Scheme counterparts, except that the index arguments are C integers, the return value for
Sstring_ref is a C character, and the return value for Sbytevector_u8_ref is an octet (unsigned char).

[macro] char Sstring_ref(ptr str, intptr i)
[macro] ptr Svector_ref(ptr vec, intptr i)
[macro] octet Sbytevector_u8_ref(ptr fxvec, intptr i)
[macro] ptr Sfxvector_ref(ptr fxvec, intptr i)

A Scheme bytevector is represented as a length field followed by a sequence of octets (unsigned chars). Sbytevector_data returns a pointer to the start of the sequence of octets. Extreme care should be taken to stop dereferencing the pointer returned by Sbytevector_data or to lock the bytevector into memory (see Slock_object below) before any Scheme code is executed, whether by calling into Scheme or returning to a Scheme caller. The storage manager may otherwise relocate or discard the object into which the pointer points and may copy other data over the object.

[macro] octet * Sbytevector_data(ptr bytevec)

Srecord_type and Srecord_type_parent correspond to the Scheme procedures record-rtd and record-type-parent. Srecord_type_size returns the allocation size in bytes of an instance of the record type. The Srecord_uniform_ref accessor should be used only on records whose fields are all Scheme values, which is a record for which Srecord_type_uniformp composed with Srecord_type returns true.

[func] ptr Srecord_type(ptr rec)
[func] ptr Srecord_type_parent(ptr rtd)
[func] uptr Srecord_type_size(ptr rtd)
[func] int Srecord_type_uniformp(ptr rtd)
[macro] ptr Srecord_uniform_ref(ptr rec, intptr i)

**Mutators.** Changes to mutable objects that contain pointers, such as pairs and vectors, must be tracked on behalf of the storage manager, as described in one of the references [13]. The operations described here perform this tracking automatically where necessary.

[func] void Sset_box(ptr box, ptr obj)
[func] void Sset_car(ptr pair, ptr obj)
[func] void Sset_cdr(ptr pair, ptr obj)
[macro] void Sstring_set(ptr str, intptr i, char c)
[func] void Svector_set(ptr vec, intptr i, ptr obj)
[macro] void Sbytevector_u8_set(ptr bytevec, intptr i, octet n)
[macro] void Sfxvector_set(ptr fxvec, intptr i, ptr fixnum)

Some Scheme objects, such as procedures and numbers, are not mutable, so no operators are provided for altering the contents of those objects.

**Constructors.** The constructors described here create Scheme objects. Some objects, such as fixnums and the empty list, are represented as immediate values that do not require
any heap allocation; others, such as pairs and vectors, are represented as pointers to heap allocated objects.

Snil, Strue, Sfalse, Sbwp_object, Seof_object, and Svoid construct constant immediate values representing the empty list (\( () \)), the boolean values (#t and #f), the broken-weak-pointer object (#!bwp), the eof object (#!eof), and the void object.

Fixnums, characters, booleans, flonums, and strings may be created from their C equivalents.

Sstring creates a Scheme copy of the C string \( s \), while Sstring_of_length creates a Scheme string of length \( n \) and copies the first \( n \) bytes from \( s \) into the new Scheme string.

If the C string is encoded in UTF-8, use Sstring_utf8 instead. Specify the number of bytes to convert as \( n \) or use \(-1\) to convert until the null terminator.

It is possible to determine whether a C integer is within fixnum range by comparing the fixnum value of a fixnum created from a C integer with the C integer:

```c
#define fixnum_rangep(x) (Sfixnum_value(Sfixnum(x)) == x)
```

Sinteger and Sunsigned may be used to create Scheme integers whether they are in fixnum range or not.

Sinteger and Sunsigned differ in their treatment of negative C integer values as well as C unsigned integer values that would appear negative if cast to integers. Sinteger converts such values into negative Scheme values, whereas Sunsigned converts such values into the appropriate positive Scheme values. For example, assuming a 32-bit, two's complement representation for iptrs, Sinteger(-1) and Sinteger((intptr)0xffffffff) both evaluate to the Scheme integer -1, whereas Sunsigned(0xffffffff) and Sunsigned((uptr)-1) both evaluate to the Scheme integer #xffffffff (4294967295).
4. Foreign Interface

Whichever routine is used, `Sinteger_value` and `Sunsigned_value` always reproduce the corresponding C input value, thus the following are all equivalent to \( x \) if \( x \) is an iptr.

\[
\begin{align*}
\text{Sinteger_value}(\text{Sinteger}(x)) \\
(iptr)\text{Sunsigned_value}(\text{Sinteger}(x)) \\
\text{Sinteger_value}(\text{Sunsigned}((uptr)x)) \\
(iptr)\text{Sunsigned_value}(\text{Sunsigned}((uptr)x))
\end{align*}
\]

Similarly, the following are all equivalent to \( x \) if \( x \) is a uptr.

\[
\begin{align*}
(uptr)\text{Sinteger_value}(\text{Sinteger}((iptr)x)) \\
\text{Sunsigned_value}(\text{Sinteger}((iptr)x)) \\
(uptr)\text{Sinteger_value}(\text{Sunsigned}(x)) \\
\text{Sunsigned_value}(\text{Sunsigned}(x))
\end{align*}
\]

`Sinteger32`, `Sunsigned32`, `Sinteger64`, and `Sunsigned64` are like the generic equivalents but restrict their arguments to the 32- or 64-bit range.

\[
\begin{align*}
\text{[func]} \text{ptr Sinteger32(Sint32_t n)} \\
\text{[func]} \text{ptr Sunsigned32(Suint32_t n)} \\
\text{[func]} \text{ptr Sinteger64(Sint64_t n)} \\
\text{[func]} \text{ptr Sunsigned64(Suint64_t n)}
\end{align*}
\]

`Scons` and `Sbox` are identical to their Scheme counterparts.

\[
\begin{align*}
\text{[func]} \text{ptr Scons(ptr obj1, ptr obj2)} \\
\text{[func]} \text{ptr Sbox(ptr obj)}
\end{align*}
\]

`Sstring_to_symbol` is similar to its Scheme counterpart, `string->symbol`, except that it takes a C string (character pointer) as input.

\[
\text{[func]} \text{ptr Sstring_to_symbol(const char *s)}
\]

`Smake_string`, `Smake_vector`, `Smake_bytevector`, and `Smake_fxvector` are similar to their Scheme counterparts.

\[
\begin{align*}
\text{[func]} \text{ptr Smake_string(iptr n, int c)} \\
\text{[func]} \text{ptr Smake_vector(iptr n, ptr obj)} \\
\text{[func]} \text{ptr Smake_bytevector(iptr n, int fill)} \\
\text{[func]} \text{ptr Smake_fxvector(iptr n, ptr fixnum)}
\end{align*}
\]

`Smake_uninitialized_string` is similar to the one-argument `make-string`.

\[
\text{[func]} \text{ptr Smake_uninitialized_string(iptr n)}
\]

**Windows-specific helper functions.** The following helper functions are provided on Windows only.

\[
\text{[func]} \text{char * Sgetenv(const char *name)}
\]
Sgetenv returns the UTF-8-encoded value of UTF-8-encoded environment variable `name` if found and NULL otherwise. Call `free` on the returned value when it is no longer needed.

```
[func] wchar_t * Sutf8_to_wide(const char *\s)
[func] char * Swide_to_utf8(const wchar_t *\s)
```

`Sutf8_to_wide` and `Swide_to_utf8` convert between UTF-8-encoded and UTF-16LE-encoded null-terminated strings. Call `free` on the returned value when it is no longer needed.

**Accessing top-level values.** Top-level variable bindings may be accessed or assigned via `Stop_level_value` and `Sset_top_level_value`.

```
[func] ptr Stop_level_value(ptr sym)
[func] void Sset_top_level_value(ptr sym, ptr obj)
```

These procedures give fast access to the bindings in the original interaction environment and do not reflect changes to the `interaction-environment` parameter or top-level module imports. To access the current interaction-environment binding for a symbol, it is necessary to call the Scheme `top-level-value` and `set-top-level-value!` procedures instead.

**Locking Scheme objects.** The storage manager periodically relocates objects in order to reclaim storage and compact the heap. This relocation is completely transparent to Scheme programs, since all pointers to a relocated object are updated to refer to the new location of the object. The storage manager cannot, however, update Scheme pointers that reside outside of the Scheme heap.

As a general rule, all pointers from C variables or data structures to Scheme objects should be discarded before entry (or reentry) into Scheme. That is, if a C procedure receives an object from Scheme or obtains it via the mechanisms described in this section, all pointers to the object should be considered invalid once the C procedure calls into Scheme or returns back to Scheme. Dereferencing an invalid pointer or passing it back to Scheme can have disastrous effects, including unrecoverable memory faults. The foregoing does not apply to immediate objects, e.g., fixnums, characters, booleans, or the empty list. It does apply to all heap-allocated objects, including pairs, vectors, strings, all numbers other than fixnums, ports, procedures, and records.

In practice, the best way to ensure that C code does not retain pointers to Scheme objects is to immediately convert the Scheme objects into C equivalents, if possible. In certain cases, it is not possible to do so, yet retention of the Scheme object is essential to the design of the C portions of the program. In these cases, the object may be locked via the library routine `Slock_object` (or from Scheme, the equivalent procedure `lock-object`).

```
[func] void Slock_object(ptr obj)
```

Locking an object prevents the storage manager from reclaiming or relocating the object. Locking should be used sparingly, as it introduces memory fragmentation and increases storage management overhead. Locking can also lead to accidental retention of storage if objects are not unlocked. Locking objects that have been made static via heap compaction (see `Scompact_heap` above) is unnecessary but harmless.
Objects may be unlocked via `Sunlock_object (unlock-object)`.

```c
void Sunlock_object(ptr obj)
```

An object may be locked more than once by successive calls to `Slock_object` or `lock-object`, in which case it must be unlocked by an equal number of calls to `Sunlock_object` or `unlock-object` before it is truly unlocked.

The function `Slocked_objectp` can be used to determine if an object is locked.

```c
int Slocked_objectp(ptr obj)
```

When a foreign procedure call is made into Scheme, a return address pointing into the Scheme code object associated with the foreign procedure is passed implicitly to the C routine. The system therefore locks the code object before calls are made from C back into Scheme and unlocks it upon return from Scheme. This locking is performed automatically; user code should never need to lock such code objects.

An object contained within a locked object, such as an object in the car of a locked pair, need not also be locked unless a separate C pointer to the object exists.

### Registering foreign entry points.

Foreign entry points may be made visible to Scheme via `Sforeign_symbol` or `Sregister_symbol`.

```c
void Sforeign_symbol(const char *name, void *addr)
void Sregister_symbol(const char *name, void *addr)
```

External entry points in object files or shared objects loaded as a result of a call to `load-shared-object` are automatically made visible by the system. Once a foreign entry point is made visible, it may be named in a `foreign-procedure` expression to create a Scheme-callable version of the entry point. `Sforeign_symbol` and `Sregister_symbol` allow programs to register nonexternal entry points, entry points in code linked statically with Chez Scheme, and entry points into code loaded directly from C, i.e., without `load-shared-object`. `Sforeign_symbol` and `Sregister_symbol` differ only in that `Sforeign_symbol` raises an exception when an attempt is made to register an existing name, whereas `Sregister_symbol` permits existing names to be redefined.

### Obtaining Scheme entry points.

`Sforeign_callable_entry_point` extracts the entry point from a code object produced by `foreign-callable`, performing the same operation as its Scheme counterpart, i.e., the Scheme procedure `foreign-callable-entry-point`.

```c
(void (*)(void)) Sforeign_callable_entry_point(ptr code)
```

This can be used to avoid converting the code object into an address until just when it is needed, which may eliminate the need to lock the code object in some circumstances, assuming that the code object is not saved across any calls back into Scheme.

The inverse translation can be made via `Sforeign_callable_code_object`.

```c
ptr Sforeign_callable_code_object((void (*)(addr)(void)))
```
4.9. C Library Routines

Low-level support for calls into Scheme. Support for calling Scheme procedures from C is provided by the set of routines documented below. Calling a Scheme procedure that expects a small number of arguments (0–3) involves the use of one of the following routines.

\[
\begin{align*}
&\text{ptr Scall0(ptr procedure)} \\
&\text{ptr Scall1(ptr procedure, ptr obj)} \\
&\text{ptr Scall2(ptr procedure, ptr obj},_1, \text{ptr obj},_2) \\
&\text{ptr Scall3(ptr procedure, ptr obj},_1, \text{ptr obj},_2, \text{ptr obj},_3)
\end{align*}
\]

In each case, the first argument, \texttt{procedure}, should be a Scheme procedure. The remaining arguments, which should be Scheme objects, are passed to the procedure. The tools described earlier in this section may be used to convert C datatypes into their Scheme equivalents. A program that automatically generates conversion code from declarations that are similar to \texttt{foreign-procedure} expressions is distributed with Chez Scheme. It can be found in the Scheme library directory on most systems in the file "foreign.ss".

A Scheme procedure may be obtained in a number of ways. For example, it may be received as an argument in a call from Scheme into C, obtained via another call to Scheme, extracted from a Scheme data structure, or obtained from the top-level environment via \texttt{Stop_level_value}.

A more general interface involving the following routines is available for longer argument lists.

\[
\begin{align*}
&\text{void Sinitframe(iptr n)} \\
&\text{void Sput_arg(iptr i, ptr obj)} \\
&\text{ptr Scall(ptr procedure, iptr n)}
\end{align*}
\]

A C procedure first calls \texttt{Sinitframe} with one argument, the number of arguments to be passed to Scheme. It then calls \texttt{Sput_arg} once for each argument (in any order), passing \texttt{Sput_arg} the argument number (starting with 1) and the argument. Finally, it calls \texttt{Scall} to perform the call, passing it the Scheme procedure and the number of arguments (the same number as in the call to \texttt{Sinitframe}). Programmers should ensure a Scheme call initiated via \texttt{Sinitframe} is completed via \texttt{Scall} before any other calls to Scheme are made and before a return to Scheme is attempted. If for any reason the call is not completed after \texttt{Sinitframe} has been called, it may not be possible to return to Scheme.

The following examples serve to illustrate both the simpler and more general interfaces.

```c
/* a particularly silly way to multiply two floating-point numbers */
double mul(double x, double y) {
    ptr times = Stop_level_value(Sstring_to_symbol("*"));
    return Sflonum_value(Scall2(times, Sflonum(x), Sflonum(y)));    
}
/* an equally silly way to call printf with five arguments */
```

/* it is best to define interfaces such as the one below to handle
* calls into Scheme to prevent accidental attempts to nest frame
* creation and to help ensure that initiated calls are completed
* as discussed above. Specialized versions tailored to particular
* C argument types may be defined as well, with embedded conversions
* to Scheme objects. */

ptr Scall5(ptr p, ptr x1, ptr x2, ptr x3, ptr x4, ptr x5) {
    Sinitframe(5);
    Sput_arg(1, x1);
    Sput_arg(2, x2);
    Sput_arg(3, x3);
    Sput_arg(4, x4);
    Sput_arg(5, x5);
    Scall(p, 5);
}

static void dumpem(char *s, int a, double b, ptr c, char *d) {
    printf(s, a, b, c, d);
}

static void foo(int x, double y, ptr z, char *s) {
    ptr ois, sip, read, expr, eval, c_dumpem;
    char *sexpr = "(foreign-procedure \"dumpem\" (string integer-32\n double-float scheme-object string) void)";

    /* this series of statements is carefully crafted to avoid referencing
    variables holding Scheme objects after calls into Scheme */
    ois = Stop_level_value(Sstring_to_symbol("open-input-string"));
    sip = Scall1(ois, Sstring(sexpr));
    read = Stop_level_value(Sstring_to_symbol("read"));
    expr = Scall1(read, sip);
    eval = Stop_level_value(Sstring_to_symbol("eval"));
    Sforeign_symbol("dumpem", (void *)dumpem);
    c_dumpem = Scall1(eval, expr);
    Scall5(c_dumpem,
            Sstring("x = %d, y = %g, z = %x, s = %s\n"),
            Sinteger(x),
            Sflonum(y),
            z,
            Sstring(s));
}

Calls from C to Scheme should not be made from C interrupt handlers. When Scheme calls
into C, the system saves the contents of certain dedicated machine registers in a register
save area. When C then calls into Scheme, the registers are restored from the register save
area. Because an interrupt can occur at any point in a computation, the contents of the
register save locations would typically contain invalid information that would cause the
Scheme system to fail to operate properly.

**Activating, deactivating, and destroying threads.** Three functions are provided by
the threaded versions of Scheme to allow C code to notify Scheme when a thread should
be activated, deactivated, or destroyed.

```c
int Sactivate_thread(void)
void Sdeactivate_thread(void)
int Sdestroy_thread(void)
```

A thread created via the Scheme procedure `fork-thread` starts in the active state and need not be activated. Any thread that has been deactivated, and any thread created by some mechanism other than `fork-thread` must, however, be activated before it can access Scheme data or execute Scheme code. A foreign callable that is declared with `__collect_safe` can activate a calling thread. Otherwise, `Sactivate_thread` must be used to activate a thread. It returns 1 the first time the thread is activated and 0 on each subsequent call until the activation is destroyed with `Sdestroy_thread`.

Since active threads operating in C code prevent the storage management system from garbage collecting, a thread should be deactivated via `Sdeactivate_thread` or through a `foreign-procedure __collect_safe` declaration whenever the thread may spend a significant amount of time in C code. This is especially important whenever the thread calls a C library function, like `read`, that may block indefinitely. Once deactivated, the thread must not touch any Scheme data or execute any Scheme code until it is reactivated, with one exception. The exception is that the thread may access or even modify a locked Scheme object, such as a locked string, that contains no pointers to other, unlocked Scheme objects. (Objects that are not locked may be relocated by the garbage collector while the thread is inactive.)

`Sdestroy_thread` is used to notify the Scheme system that the thread is shut down and any thread-specific data can be released.

**Low-level synchronization primitives.** The header file defines several preprocessor macros that can be used to lock memory locations in a manner identical to the corresponding ftype lock operations (sections 15.4 and 15.5).

```c
void INITLOCK(void *addr)
void SPINLOCK(void *addr)
void UNLOCK(void *addr)
void LOCKED_INCR(void *addr, int *ret)
void LOCKED_DECR(void *addr, int *ret)
```

`LOCKED_INCR` and `LOCKED_DECR` set `ret` to a nonzero (true) value if the incremented or decremented value is 0. Otherwise they set `ret` to 0.

### 4.10. Example: Socket Operations

This section presents a simple socket interface that employs a combination of Scheme and C code. The C code defines a set of convenient low-level operating-system interfaces that can be used in the higher-level Scheme code to open, close, read from, and write to sockets.
The C code (csocket.c) is given below, followed by the Scheme code (socket.ss). The code should require little or no modification to run on most Unix systems and can be modified to work under Windows (using the Windows WinSock interface).

A sample session demonstrating the socket interface follows the code. See Section 9.17 for an example that demonstrates how to use the same socket interface to build a process port that allows transparent input from and output to a subprocess via a Scheme port.

C code.

/* csocket.c */
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <string.h>
#include <errno.h>
#include <signal.h>
#include <sys/ioctl.h>
#include <stdio.h>
#include <unistd.h>

/* c_write attempts to write the entire buffer, pushing through interrupts, socket delays, and partial-buffer writes */
int c_write(int fd, char *buf, ssize_t start, ssize_t n) {
    ssize_t i, m;
    buf += start;
    m = n;
    while (m > 0) {
        if ((i = write(fd, buf, m)) < 0) {
            if (errno != EAGAIN && errno != EINTR)
                return i;
        } else {
            m -= i;
            buf += i;
        }
    }
    return n;
}

/* c_read pushes through interrupts and socket delays */
int c_read(int fd, char *buf, size_t start, size_t n) {
    int i;
    buf += start;
    for (;;) {
        i = read(fd, buf, n);
        if (i >= 0) return i;
        if (errno != EAGAIN && errno != EINTR) return -1;
    }
}
/* bytes_ready(fd) returns true if there are bytes available
to be read from the socket identified by fd */
int bytes_ready(int fd) {
    int n;
    (void) ioctl(fd, FIONREAD, &n);
    return n;
}

/* socket support */
/* do_socket() creates a new AF_UNIX socket */
int do_socket(void) {
    return socket(AF_UNIX, SOCK_STREAM, 0);
}

/* do_bind(s, name) binds name to the socket s */
int do_bind(int s, char *name) {
    struct sockaddr_un sun;
    int length;
    sun.sun_family = AF_UNIX;
    (void) strcpy(sun.sun_path, name);
    length = sizeof(sun.sun_family) + sizeof(sun.sun_path);
    return bind(s, (struct sockaddr*)(&sun), length);
}

/* do_accept accepts a connection on socket s */
int do_accept(int s) {
    struct sockaddr_un sun;
    socklen_t length;
    length = sizeof(sun.sun_family) + sizeof(sun.sun_path);
    return accept(s, (struct sockaddr*)(&sun), &length);
}

/* do_connect initiates a socket connection */
int do_connect(int s, char *name) {
    struct sockaddr_un sun;
    int length;
    sun.sun_family = AF_UNIX;
    (void) strcpy(sun.sun_path, name);
    length = sizeof(sun.sun_family) + sizeof(sun.sun_path);
    return connect(s, (struct sockaddr*)(&sun), length);
}

/* get_error returns the operating system's error status */
char* get_error(void) {
    extern int errno;
return strerror(errno);
}

Scheme code.

;;; socket.ss

;;; Requires csocket.so, built from csocket.c.
(load-shared-object "./csocket.so")

;;; Requires from C library:
;;; close, dup, execl, fork, kill, listen, tmpnam, unlink
(case (machine-type)
  [(i3le ti3le a6le ta6le) (load-shared-object "libc.so.6")]
  [(i3osx ti3osx a6osx ta6osx) (load-shared-object "libc.dylib")]
  [else (load-shared-object "libc.so")])

;;; basic C-library stuff

(define close
  (foreign-procedure "close" (int)
   int))

(define dup
  (foreign-procedure "dup" (int)
   int))

(define execl4
  (let ((execl-help
         (foreign-procedure "execl"
          (string string string string void*)
          int)))
   (lambda (s1 s2 s3 s4)
     (execl-help s1 s2 s3 s4 0))))

(define fork
  (foreign-procedure "fork" ()
   int))

(define kill
  (foreign-procedure "kill" (int int)
   int))

(define listen
  (foreign-procedure "listen" (int int)
   int))

(define tmpnam
  (foreign-procedure "tmpnam" (void*)
   string))

(define unlink
  (foreign-procedure "unlink" (string)
### 4.10. Example: Socket Operations

```scheme
(int)

;;; routines defined in csocket.c

(define accept
  (foreign-procedure "do_accept" (int)
    int))

(define bytes-ready?
  (foreign-procedure "bytes_ready" (int)
    boolean))

(define bind
  (foreign-procedure "do_bind" (int string)
    int))

(define c-error
  (foreign-procedure "get_error" ()
    string))

(define c-read
  (foreign-procedure "c_read" (int u8* size_t size_t)
    ssize_t))

(define c-write
  (foreign-procedure "c_write" (int u8* size_t ssize_t)
    ssize_t))

(define connect
  (foreign-procedure "do_connect" (int string)
    int))

(define socket
  (foreign-procedure "do_socket" ()
    int))

;;; higher-level routines

(define dodup
  ; (dodup old new) closes old and dups new, then checks to
  ; make sure that resulting fd is the same as old
  (lambda (old new)
    (check 'close (close old))
    (unless (= (dup new) old)
      (error 'dodup
        "couldn't set up child process io for fd -s" old))))

(define dofork
  ; (dofork child parent) forks a child process and invokes child
  ; without arguments and parent with the child's pid
  (lambda (child parent)
    (let ([pid (fork)])
      (cond
        [(= pid 0) (child)]))
```
[(> pid 0) (parent pid)]
[else (error 'fork (c-error))]]))

(define setup-server-socket
 ; create a socket, bind it to name, and listen for connections
 (lambda (name)
   (let ([sock (check 'socket (socket))]
         [unlink name]
         [bind (bind sock name)]
         [listen (listen sock 1)]
         [sock])))

(define setup-client-socket
 ; create a socket and attempt to connect to server
 (lambda (name)
   (let ([sock (check 'socket (socket))]
         [connect (connect sock name)]
         [sock])))

(define accept-socket
 ; accept a connection
 (lambda (sock)
   (check 'accept (accept sock))))

(define check
 ; signal an error if status x is negative, using c-error to
 ; obtain the operating-system’s error message
 (lambda (who x)
   (if (< x 0)
     (error who (c-error))
     x)))

(define terminate-process
 ; kill the process identified by pid
 (lambda (pid)
   (define sigterm 15)
   (kill pid sigterm)
   (void)))

Sample session.

> (define client-pid)
> (define client-socket)
> (let* ([server-socket-name (tmpnam 0)]
   [server-socket (setup-server-socket server-socket-name)])
 ; fork a child, use it to exec a client Scheme process, and set
 ; up server-side client-pid and client-socket variables.
 (dofork ; child
   (lambda ()
     ; the child establishes the socket input/output fds as
     ; stdin and stdout, then starts a new Scheme session

(check 'close (close server-socket))
(let ([sock (setup-client-socket server-socket-name)])
  (dodup 0 sock)
  (dodup 1 sock))
(check 'exec1 (exec14 "/bin/sh" "/bin/sh" "-c" "exec scheme -q")
(errorf 'client "returned!"))
(lambda (pid) ; parent
  ; the parent waits for a connection from the client
  (set! client-pid pid)
  (set! client-socket (accept-socket server-socket))
  (check 'close (close server-socket))))
> (define put ; procedure to send data to client
  (lambda (x)
    (let ([s (format "~s~%" x)])
      (c-write client-socket s (string-length s)))
    (void)))
> (define get ; procedure to read data from client
  (let ([buff (make-string 1024)])
    (lambda ()
      (let ([n (c-read client-socket buff (string-length buff))])
        (printf "client:~%~a~%server:~%" (substring buff 0 n)))))
> (get)
server:
> (put '(let ([x 3]) x))
> (get)
client:
3
server:
> (terminate-process client-pid)
> (exit)
5. Binding Forms

This chapter describes Chez Scheme extensions to the set of Revised\textsuperscript{6} Report binding forms. See Chapter 4 of \textit{The Scheme Programming Language, 4th Edition} or the Revised\textsuperscript{6} Report for a description of standard binding forms.

5.1. Definitions

A definition in Revised\textsuperscript{6} Report Scheme is a variable definition, keyword definition, or derived definition, i.e., a syntactic extension that expands into a definition. In addition, the forms within a \texttt{begin} expression appearing after a sequence of definitions is spliced onto the end of the sequence of definitions so that definitions at the front of the \texttt{begin} expression are treated as if they were part of the outer sequence of definitions. A \texttt{let-syntax} or \texttt{letrec-syntax} form is treated similarly, so that definitions at the front of the body are treated as if they were part of the outer sequence of definitions, albeit scoped where the bindings of the \texttt{let-syntax} or \texttt{letrec-syntax} form are visible.

Chez Scheme extends the set of definitions to include \texttt{module} forms, \texttt{import} forms, \texttt{import-only} forms, \texttt{meta} definitions, and \texttt{alias} forms, although the \texttt{module}, \texttt{import}, \texttt{import-only}, \texttt{meta}, and \texttt{alias} keywords are not available in a library or RNRS top-level program unless the \texttt{scheme} library is included in the library or top-level programs imports. These forms are described in Chapter \ref{ch:import-import-only-module-meta-alias}.

In Revised\textsuperscript{6} Report Scheme, definitions can appear at the front of a \texttt{lambda} or similar body (e.g., a \texttt{let} or \texttt{letrec} body), at the front of a library body, or intermixed with expressions within an RNRS top-level program body. In Chez Scheme, definitions may also be used in the interactive top-level, i.e., they can be intermixed with expressions in the REPL or in program text to be loaded from a file via \texttt{load} (Section \ref{sec:load}). The Revised\textsuperscript{6} Report does not mandate the existence nor specify the semantics of an interactive top-level, nor of a \texttt{load} procedure.

The macro expander uses the same two-pass algorithm for expanding top-level \texttt{begin} expressions as it uses for a \texttt{lambda}, \texttt{library}, or top-level program body. (This algorithm is described in Section \ref{sec:2pass} of \textit{The Scheme Programming Language, 4th Edition}.) As a result,

\begin{verbatim}
(beg
  (define-syntax a (identifier-syntax 3))
  (define x a))
\end{verbatim}
and

(begin
  (define x a)
  (define-syntax a (identifier-syntax 3)))

both result in the giving \( x \) the value 3, even though an unbound variable reference to \( a \) would result if the two forms within the latter \begin{verbatim}{}end\end{verbatim} expression were run independently at top level.

Similarly, the \begin{verbatim}{}end\end{verbatim} form produced by a use of

(define-syntax define-constant
  (syntax-rules ()
    [(_ x e)
      (begin
        (define t e)
        (define-syntax x (identifier-syntax t))))
  )

and the \begin{verbatim}{}end\end{verbatim} form produced by a use of

(define-syntax define-constant
  (syntax-rules ()
    [(_ x e)
      (begin
        (define-syntax x (identifier-syntax t))
        (define t e))]))

are equivalent.

The Revised\(^6\) Report specifies that internal variable definitions be treated like \texttt{letrec*}, while earlier reports required internal variable definitions to be treated like \texttt{letrec}. By default, Chez Scheme implements the Revised\(^6\) Report semantics for internal variable definitions, as for all other things, but this behavior may be overridden via the \texttt{internal-defines-as-letrec*} parameter.

**internal-defines-as-letrec* thread parameter**

libraries: (chezscheme)

When this parameter is set to \#t (the default), internal variable definitions are evaluated using \texttt{letrec*} semantics. It may be set to \#f to revert to the \texttt{letrec} semantics for internal variable definitions, for backward compatibility.

### 5.2. Multiple-value Definitions

\begin{verbatim}{}define-values formals expr\end{verbatim}

libraries: (chezscheme)

A \texttt{define-values} form is a definition and can appear anywhere other definitions can appear.
It is like a define form but permits an arbitrary formals list (like lambda) on the left-hand side. It evaluates expr and binds the variables appearing in formals to the resulting values, in the same manner as the formal parameters of a procedure are bound to its arguments.

(let ()
  (define-values (x y) (values 1 2))
  (list x y)) ⇒ (1 2)
(let ()
  (define-values (x y . z) (values 1 2 3 4))
  (list x y z)) ⇒ (1 2 (3 4))

A define-values form expands into a sequence of definitions, the first for a hidden temporary bound to a data structure holding the values returned by expr and the remainder binding each of the formals to the corresponding value or list of values, extracted from the data structure via a reference to the temporary. Because the temporary must be defined before the other variables are defined, this works for internal define-values forms only if internal-defines-as-letrec* is set to the default value #t.

5.3. Recursive Bindings

(rec var expr) syntax
returns: value of expr
libraries: (chezscheme)

The syntactic form rec creates a recursive object from expr by establishing a binding of var within expr to the value of expr. In essence, it is a special case of letrec for self-recursive objects.

This form is useful for creating recursive objects (especially procedures) that do not depend on external variables for the recursion, which are sometimes undesirable because the external bindings can change. For example, a recursive procedure defined at top level depends on the value of the top-level variable given as its name. If the value of this variable should change, the meaning of the procedure itself would change. If the procedure is defined instead with rec, its meaning is independent of the variable to which it is bound.

(map (rec sum
  (lambda (x)
    (if (= x 0)
      0
      (+ x (sum (- x 1)))))
  '(0 1 2 3 4 5)) ⇒ (0 1 3 6 10 15)
(define cycle
  (rec self
    (list (lambda () self))))
(eq? ((car cycle)) cycle) ⇒ #t

The definition below expands rec in terms of letrec.
(define-syntax rec
  (syntax-rules ()
    [(_ x e) (letrec ((x e)) x)]))

5.4. Fluid Bindings

(fluid-let ((var expr) ...) body_1 body_2 ...)

**syntax** returns: the values of the body body_1 body_2 ...

**libraries:** (chezscheme)

The syntactic form `fluid-let` provides a way to temporarily assign values to a set of variables. The new values are in effect only during the evaluation of the body of the `fluid-let` expression. The scopes of the variables are not determined by `fluid-let`; as with `set!`, the variables must be bound at top level or by an enclosing `lambda` or other binding form. It is possible, therefore, to control the scope of a variable with `lambda` or `let` while establishing a temporary value with `fluid-let`.

Although it is similar in appearance to `let`, its operation is more like that of `set!`. Each `var` is assigned, as with `set!`, to the value of the corresponding `expr` within the body body_1 body_2 .... Should the body exit normally or by invoking a continuation made outside of the body (see `call/cc`), the values in effect before the bindings were changed are restored. Should control return back to the body by the invocation of a continuation created within the body, the bindings are changed once again to the values in effect when the body last exited.

Fluid bindings are most useful for maintaining variables that must be shared by a group of procedures. Upon entry to the group of procedures, the shared variables are fluidly bound to a new set of initial values so that on exit the original values are restored automatically. In this way, the group of procedures itself can be reentrant; it may call itself directly or indirectly without affecting the values of its shared variables.

Fluid bindings are similar to special bindings in Common Lisp [30], except that (1) there is a single namespace for both lexical and fluid bindings, and (2) the scope of a fluidly bound variable is not necessarily global.

(let ([x 3])
  (+ (fluid-let ([x 5])
       x)
     x)) ⇒ 8

(let ([x 'a])
  (letrec ([f (lambda (y) (cons x y))])
    (fluid-let ([x 'b])
      (f 'c))) ) ⇒ (b . c)

(let ([x 'a])
  (call/cc
    (lambda (k)
      (fluid-let ([x 'b])
        ...)))

(let ([x 'a])
  (call/cc
    (lambda (k)
      (fluid-let ([x 'b])
        ...)))

(let ([x 'a])
  (call/cc
    (lambda (k)
      (fluid-let ([x 'b])
        ...)))

(let ([x 'a])
  (call/cc
    (lambda (k)
      (fluid-let ([x 'b])
        ...)))
(letrec ([f (lambda (y) (k '*))])
  (f '*)))))
x) ⇒ a

fluid-let may be defined in terms of dynamic-wind as follows.

(define-syntax fluid-let
  (lambda (x)
    (syntax-case x ()
      [(_ () b1 b2 ...) #'(let () b1 b2 ...)]
      [(_ ((x e) ...) b1 b2 ...) (andmap identifier? #'(x ...))]
      [(_ (x e) ...) (with-syntax ([(y ...) (generate-temporaries #'(x ...))])
                    #'(let ([y e] ...)
                        (let ([swap (lambda ()
                              (let ([t x]) (set! x y) (set! y t))
                              ...)])
                            (dynamic-wind swap (lambda () b1 b2 ...) swap))))))))

5.5. Top-Level Bindings

The procedures described in this section allow the direct manipulation of top-level bindings for variables and keywords. They are intended primarily to support the definition of interpreters or compilers for Scheme in Scheme but may be used to access or alter top-level bindings anywhere within a program whether at top level or not.

(define-top-level-value symbol obj)
(define-top-level-value symbol obj env)
returns: unspecified
libraries: (chezscheme)

define-top-level-value is used to establish a binding for the variable named by symbol to the value obj in the environment env. If env is not provided, it defaults to the value of interaction-environment, i.e., the top-level evaluation environment (Section 12.3). An exception is raised with condition type &assertion if env is not mutable.

A call to define-top-level-value is similar to a top-level define form, except that a call to define-top-level-value need not occur at top-level and the variable for which the binding is to be established can be determined at run time, as can the environment.

(begin
  (define-top-level-value 'xyz "hi")
xyz) ⇒ "hi"

(let ([var 'xyz])
  (define-top-level-value var "mom")
  (list var xyz)) ⇒ (xyz "mom")
set-top-level-value! assigns the variable named by `symbol` to the value `obj` in the environment `env`. If `env` is not provided, it defaults to the value of interaction-environment, i.e., the top-level evaluation environment (Section 12.3).

An exception is raised with condition type &assertion if the identifier named by `symbol` is not defined as a variable in `env` or if the variable or environment is not mutable.

set-top-level-value! is similar to set! when set! is used on top-level variables except that the variable to be assigned can be determined at run time, as can the environment.

\[
\begin{align*}
\text{(let ([cons list])} \\
\text{\quad (set-top-level-value! 'cons +)} \\
\text{\quad (cons 3 4))})
\end{align*}
\]
\[
\Rightarrow (3 4)
\]

(top-level-value `symbol`) procedure
(top-level-value `symbol env`) procedure
returns: the top-level value of the variable named by `symbol` in `env`
libraries: (chezscheme)

If `env` is not provided, it defaults to the value of interaction-environment, i.e., the top-level evaluation environment (Section 12.3).

An exception is raised with condition type &assertion if the identifier named by `symbol` is not defined as a variable in `env`.

top-level-value is similar to a top-level variable reference except that the variable to be referenced can be determined at run time, as can the environment.

\[
\begin{align*}
\text{(let ([cons +])} \\
\text{\quad (list (cons 3 4))} \\
\text{\quad ((top-level-value 'cons) 3 4))}) \Rightarrow (3 4)
\end{align*}
\]

(define e (copy-environment (scheme-environment)))
(define-top-level-value 'pi 3.14 e)
(top-level-value 'pi e) \Rightarrow 3.14
(set-top-level-value! 'pi 3.1416 e)
(top-level-value 'pi e) \Rightarrow 3.1416
level evaluation environment (Section 12.3).

This predicate is useful in an interpreter to check for the existence of a top-level binding before requesting the value with `top-level-value`.

\[(\text{top-level-bound? } '\text{xyz}) \Rightarrow \#f\]

\[(\text{begin}\
  (\text{define-top-level-value} '\text{xyz} 3)\
  (\text{top-level-bound? } '\text{xyz})) \Rightarrow \#t\]

\[(\text{define e (copy-environment (interaction-environment)))}\
(\text{define-top-level-value} '\text{pi} 3.14 \text{e})\
(\text{top-level-bound? } '\text{pi}) \Rightarrow \#f\
(\text{top-level-bound? } '\text{pi} \text{e}) \Rightarrow \#t\]

\[(\text{top-level-mutable? symbol})\]
\[(\text{top-level-mutable? symbol env})\]

returns: \#t if `symbol` is mutable in `env`, \#f otherwise

libraries: (chezscheme)

If `env` is not provided, it defaults to the value of `interaction-environment`, i.e., the top-level evaluation environment (Section 12.3).

This predicate is useful in an interpreter to check whether a variable can be assigned before assigning it with `set-top-level-value!`.

\[(\text{define xyz} 3)\]
\[(\text{top-level-mutable? } '\text{xyz}) \Rightarrow \#t\]
\[(\text{set-top-level-value!} '\text{xyz} 4)\]
\[(\text{top-level-value } '\text{xyz}) \Rightarrow 4\]

\[(\text{define e (copy-environment (interaction-environment) #f))}\
(\text{top-level-mutable? } '\text{xyz} \text{e}) \Rightarrow \#f\
(\text{set-top-level-value!} '\text{xyz} \text{e}) \Rightarrow \text{exception: xyz is immutable}\]

\[(\text{define-top-level-syntax symbol obj})\]
\[(\text{define-top-level-syntax symbol obj env})\]

returns: unspecified

libraries: (chezscheme)

\text{define-top-level-syntax} is used to establish a top-level binding for the identifier named by `symbol` to the value of `obj` in the environment `env`. The value must be a procedure, the result of a call to `make-variable-transformer`, or the result of a call to `top-level-syntax`. If `env` is not provided, it defaults to the value of `interaction-environment`, i.e., the top-level evaluation environment (Section 12.3).

An exception is raised with condition type \&assertion if `env` is not mutable.

A call to `define-top-level-syntax` is similar to a top-level `define-syntax` form, except that a call to `define-top-level-syntax` need not occur at top-level and the identifier
for which the binding is to be established can be determined at run time, as can the environment.

```scheme
(define-top-level-syntax 'let1
  (syntax-rules ()
    [(_ x e b1 b2 ...) (let ([x e]) b1 b2 ...)]))
(let1 a 3 (+ a 1))  ⇒  4
```

`define-top-level-syntax` can also be used to attach to an identifier arbitrary compile-time bindings obtained via `top-level-syntax`.

```scheme
(define-top-level-syntax 'also-let (top-level-syntax 'let))
(also-let ([x 3] [y 4]) (+ x y))  ⇒  7
```

An exception is raised with condition type `&assertion` if the identifier named by `symbol` is not defined as a keyword in `env`.

```scheme
(define foo 17)
(define-top-level-syntax 'also-foo (top-level-syntax 'foo))
also-foo  ⇒  17
(set! also-foo 23)
also-foo  ⇒  23
foo  ⇒  23
```

The effect of the last example can be had more clearly with `alias`:

```scheme
(define foo 17)
(alias also-foo foo)
also-foo  ⇒  17
(set! also-foo 23)
also-foo  ⇒  23
foo  ⇒  23
```
5.5. Top-Level Bindings

\begin{verbatim}
(top-level-syntax? symbol) procedure
(top-level-syntax? symbol env) procedure
returns: #t if symbol is bound as a keyword in env, #f otherwise
libraries: (chezscheme)
\end{verbatim}

If \textit{env} is not provided, it defaults to the value of \texttt{interaction-environment}, i.e., the top-level evaluation environment (Section 12.3).

All identifiers bound in an environment have compile-time bindings, including variables, so this predicate amounts to a bound check, but is more general than \texttt{top-level-bound?}, which returns true only for bound variables.

\begin{verbatim}
(define xyz 'hello)
(top-level-syntax? 'cons) ⇒ #t
(top-level-syntax? 'lambda) ⇒ #t
(top-level-syntax? 'hello) ⇒ #t
(top-level-syntax? 'cons (scheme-environment)) ⇒ #t
(top-level-syntax? 'lambda (scheme-environment)) ⇒ #t
(top-level-syntax? 'hello (scheme-environment)) ⇒ #f
\end{verbatim}
6. Control Structures

This chapter describes Chez Scheme extensions to the set of standard control structures. See Chapter 5 of The Scheme Programming Language, 4th Edition or the Revised Report on Scheme for a description of standard control structures.

6.1. Conditionals

(exclusive-cond clause1 clause2 ...) syntax
returns: see below
libraries: (chezscheme)

exclusive-cond is a version of cond (Section 5.3 of TSPLFOUR) that differs from cond in that the tests embedded within the clauses are assumed to be exclusive in the sense that if one of the tests is true, the others are not. This allows the implementation to reorder clauses when profiling information is available at expansion time (Section 12.7).

The (test) form of clause is not supported. The order chosen when profiling information is available is based on the relative numbers of times the RHS of each clause is executed, and (test => values) is equivalent, albeit less concise.

(case expr0 clause1 clause2 ...) syntax
returns: see below
libraries: (chezscheme)

Each clause but the last must take one of the forms:

((key ...) expr1 expr2 ...)  
(key expr1 expr2 ...)

where each key is a datum distinct from the other keys. The last clause may be in the above form or it may be an else clause of the form

(else expr1 expr2 ...)

expr0 is evaluated and the result is compared (using equal?) against the keys of each clause in order. If a clause containing a matching key is found, the expressions expr1 expr2 ... are evaluated in sequence and the values of the last expression are returned.
If none of the clauses contains a matching key and an else clause is present, the expressions $expr_1 \; expr_2 \; ...$ of the else clause are evaluated in sequence and the values of the last expression are returned.

If none of the clauses contains a matching key and no else clause is present, the value or values are unspecified.

The Revised$^6$ Report version of case does not support singleton keys (the second of the first two clause forms above) and uses eqv? rather than equal? as the comparison procedure. Both versions are defined in terms of exclusive-cond so that if profiling information is available at expansion time, the clauses will be reordered to put those that are most frequently executed first.

```scheme
(let ([ls '(ii iv)])
  (case (car ls)
    [i 1]
    [ii 2]
    [iii 3]
    [(iiv iv) 4]
    [else 'out-of-range]]) ⇒ 2)

(define p
  (lambda (x)
    (case x
      ["abc" "def") 'one]
      [((a b c)) 'two]
      [else #f])))

(p (string #\d #\e #\f)) ⇒ one
(p '(a b c)) ⇒ two

(\texttt{record-case} \; expr \; clause_1 \; clause_2 \; ... \) \textbf{syntax}

returns: see explanation

libraries: (chezscheme)

record-case is a restricted form of case that supports the destructuring of records, or tagged lists. A record has as its first element a tag that determines what “type” of record it is; the remaining elements are the fields of the record.

Each clause but the last must take the form

\[(key \; ...) \; formals \; body_1 \; body_2 \; ...)\]

where each key is a datum distinct from the other keys. The last clause may be in the above form or it may be an else clause of the form

\[(else \; body_1 \; body_2 \; ... )\]

expr must evaluate to a pair. expr is evaluated and the car of its value is compared (using eqv?) against the keys of each clause in order. If a clause containing a matching key is found, the variables in formals are bound to the remaining elements of the list and the expressions $body_1 \; body_2 \; ...$ are evaluated in sequence. The value of the last expression is
returned. The effect is identical to the application of

\[(\text{lambda formals body}_1 \text{ body}_2 \ldots)\]

to the cdr of the list.

If none of the clauses contains a matching key and an \texttt{else} clause is present, the expressions \texttt{body}_1 \texttt{ body}_2 \ldots of the \texttt{else} clause are evaluated in sequence and the value of the last expression is returned.

If none of the clauses contains a matching key and no \texttt{else} clause is present, the value is unspecified.

\[
(\text{define calc}
(\text{lambda (x)}
  (\text{record-case x}
    [(\text{add}) (x y) (+ x y)]
    [(\text{sub}) (x y) (- x y)]
    [(\text{mul}) (x y) (* x y)]
    [(\text{div}) (x y) (/ x y)]
    [\text{else} (\text{assertion-violationf 'calc "invalid expression ~s" x})]]))
\]

(calc '(add 3 4)) \Rightarrow 7
(calc '(div 3 4)) \Rightarrow 3/4

6.2. Mapping and Folding

\[(\text{ormap procedure list}_1 \text{ list}_2 \ldots)\]

\textbf{returns:} see explanation

\textbf{libraries:} (chezscheme)

\texttt{ormap} is identical to the Revised\textsuperscript{6} Report \texttt{exists}.

\[(\text{andmap procedure list}_1 \text{ list}_2 \ldots)\]

\textbf{returns:} see explanation

\textbf{libraries:} (chezscheme)

\texttt{andmap} is identical to the Revised\textsuperscript{6} Report \texttt{for-all}.

6.3. Continuations

\textit{Chez Scheme} supports one-shot continuations as well as the standard multi-shot continuations obtainable via \texttt{call/cc}. One-shot continuations are continuations that may be invoked at most once, whether explicitly or implicitly. They are obtained with \texttt{call/1cc}.

Continuation \textit{marks} support efficient annotation of continuations and inspection of those annotations. Each continuation has a table of marks, where each mark is a key–value pair. This table is updated using the \texttt{with-continuation-mark} form to associate a
key with a value, replacing any existing association for that key. Although each con-
tinuation has a single immediate table of marks, a continuation may extend another
continuation that has its own marks. The current-continuation-marks function cap-
tures the sequence of mark tables for a continuation and all continuations that it ex-
tends. Functions such as continuation-marks-first, continuation-marks->list, and
continuation-marks->iterator can be used to inspect mark sequences. When a con-
tinuation is captured with call/cc, only the marks of the rest of the continuation are
captured, and continuation-next-marks returns the captured marks.

\begin{verbatim}
(call/1cc procedure) procedure
returns: see below
libraries: (chezscheme)
\end{verbatim}

call/1cc obtains its continuation and passes it to procedure, which should accept one
argument. The continuation itself is represented by a procedure. This procedure normally
takes one argument but may take an arbitrary number of arguments depending upon
whether the context of the call to call/1cc expects multiple return values or not. When
this procedure is applied to a value or values, it returns the values to the continuation of the
call/1cc application.

The continuation obtained by call/1cc is a “one-shot continuation.” A one-shot con-
tinuation should not be returned to multiple times, either by invoking the continuation or
returning normally from procedure more than once. A one-shot continuation is “pro-
moted” into a normal (multishot) continuation, however, if it is still active when a normal
continuation is obtained by call/cc. After a one-shot continuation is promoted into a
multishot continuation, it behaves exactly as if it had been obtained via call/cc. This
allows call/cc and call/1cc to be used together transparently in many applications.

One-shot continuations may be more efficient for some applications than multishot contin-
uations. See the paper “Representing control in the presence of one-shot continuations” [3]
for more information about one-shot continuations, including how they are implemented
in Chez Scheme.

The following examples highlight the similarities and differences between one-shot and
normal continuations.

(\begin{verbatim}
define prod
  ; compute the product of the elements of ls, bugging out
  ; with no multiplications if a zero element is found
  (lambda (ls)
    (lambda (k)
      (if (null? ls)
        1
        (if (= (car ls) 0)
          (k 0)
          (* (car ls) ((prod (cdr ls)) k))))))
\end{verbatim})

\begin{verbatim}
(call/cc (prod '(1 2 3 4))) ⇒ 24
(call/1cc (prod '(1 2 3 4))) ⇒ 24
\end{verbatim}
6.3. Continuations

(call/cc (prod '(1 2 3 4 0)))  ⇒  0
(call/cc (prod '(1 2 3 4 0)))  ⇒  0

(let ([k (call/cc (lambda (x) x))])
  (k (lambda (x) 0)))  ⇒  0

(let ([k (call/cc (lambda (x) x))])
  (k (lambda (x) 0)))  ⇒  exception

(dynamic-wind in body out)  procedure
(dynamic-wind critical? in body out)  procedure

returns: values resulting from the application of body
libraries: (chezscheme)

The first form is identical to the Revised\textsuperscript{6} Report \texttt{dynamic-wind}. When the optional \texttt{critical?} argument is present and non-false, the \texttt{in} thunk is invoked in a critical section along with the code that records that the body has been entered, and the \texttt{out} thunk is invoked in a critical section along with the code that records that the body has been exited. Extreme caution must be taken with this form of \texttt{dynamic-wind}, since an error or long-running computation can leave interrupts and automatic garbage collection disabled.

(with-continuation-mark key val body)  syntax

returns: the value of the body expression
libraries: (chezscheme)

\texttt{with-continuation-mark} updates the table of marks on the current continuation to map the result of the \texttt{key} expression to the result of the \texttt{val} expression. If the current continuation’s table of marks already has a mapping for \texttt{key} (based on \texttt{eq?} comparison), then the mark’s value is replaced with \texttt{val}, otherwise a mapping from \texttt{key} to \texttt{val} is added to the table.

(with-continuation-mark
  'key "val"
  "hello"); => "hello"

(with-continuation-mark
  'key "val"
  (continuation-marks-first (current-continuation-marks)
    'key)); => "val"

(with-continuation-mark
  'key "val"
  (continuation-marks-first (current-continuation-marks)
    'other-key)); => #f

(with-continuation-mark
  'key "val"
  (with-continuation-mark
    'key "val2"
(continuation-marks-first (current-continuation-marks) 'key)); => "val2"

(with-continuation-mark 'key "val"
  (with-continuation-mark 'key "val2"
    (continuation-marks->list (current-continuation-marks) 'key)); => ("val2")

(with-continuation-mark 'key "val"
  (values
    (with-continuation-mark 'key "val2"
      (continuation-marks->list (current-continuation-marks) 'key))))); => ("val2" "val")

(continuation-marks? obj) procedure
returns: boolean
libraries: (chezscheme)

A predicate that recognizes a continuation mark sequence, which can be produced by the functions current-continuation-marks and continuation-next-marks.

(current-continuation-marks) procedure
(continuation-next-marks cont) procedure
returns: a continuation mark sequence
libraries: (chezscheme)

Returns a captured sequence of mark tables, either the current continuation’s marks in the case of current-continuation-marks or the marks of the rest of cont in the case of continuation-next-marks. In the latter case, cont must be a continuation.

This function takes constant time. The size of the resulting mark sequence is proportional to the number of distinct key–value mappings in the overall mark-table sequence; that size is bounded by the length of the continuation times the number of distinct values used as keys, but since many continuations have no keys or fewer than all possible keys in their tables, the size tends to be much less than the bound.

(continuation-marks? (current-continuation-marks)); => #t
(continuation-marks? (continuation-next-marks (call/cc (lambda (k) k)))); => #t
6.3. Continuations

<table>
<thead>
<tr>
<th>(continuation-marks-first marks key)</th>
<th>procedure</th>
<th>returns: the value for key in marks or none-val</th>
</tr>
</thead>
<tbody>
<tr>
<td>(continuation-marks-first marks key none-val)</td>
<td>procedure</td>
<td>libraries: (chezscheme)</td>
</tr>
</tbody>
</table>

Extracts the first value found for key in marks, checking the mark table of a continuation before checking the table of the continuation that it extends (if any). Keys are compared using eq?. If no mark for key is found, none-val is returned; if none-val is not provided, it defaults to #f.

This function takes amortized time proportional to the number of distinct values used as keys in marks. Typically the number of keys used in an application is bounded, which makes the computation amortized constant-time for those applications.

| (with-continuation-mark 'key "val" (values (with-continuation-mark 'key "val2" (continuation-marks-first (current-continuation-marks) 'key))) ) | => "val2" |
| (with-continuation-mark 'key "val" (continuation-marks-first (current-continuation-marks) 'other "nope") ) | => "nope" |

<table>
<thead>
<tr>
<th>(continuation-marks-&gt;list marks key)</th>
<th>procedure</th>
<th>returns: a list</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Returns the list of all values associated with key in marks, with the value from a continuation’s mark table appearing before the values from the mark tables of any other continuation that it extends. Keys are compared using eq?.

This function takes time proportional to the size of the captured mark sequence.

| (with-continuation-mark 'key "val" (values (with-continuation-mark 'key "val2" (continuation-marks->list (current-continuation-marks) 'key))) ) | => ("val2" "val") |
| (with-continuation-mark 'key "val" (continuation-marks->list (current-continuation-marks) 'other)) | => () |
Generalizes the mark sequence traversal of `continuation-marks->list` to a functional iterator. The `marks` argument must be a continuation mark sequence, and the `key-vector` argument must be a vector of values to be used as keys. The result is an iterator procedure of zero arguments.

Calling the result iterator procedure (with no arguments) returns two values:

- The first result is either a vector of values, one for each key in `key-vector` (in the order given in `key-vector`) and drawn from a single continuation’s mark table, or `#f` if no more values for any keys are available. The given `none-val`, which defaults to `#f`, is used for each key that has no value in the table. Only mark tables with mappings for at least one of the keys in `key-vector` are represented in the iteration, so a result vector will never consist solely of `none-val` values (unless one or more of the keys is explicitly mapped to `none-val`).

- The second result is a new iterator procedure to obtain the next vector of values, and so on. When the first result is `#f`, the second result is an iterator procedure that will still return `#f` as its first result (and a procedure functionally equivalent to itself as the second result).

Obtaining an iterator from `continuation-marks->iterator` takes constant time. Each call to an iterator takes time proportional to the size of continuation mark tables that are traversed to find one of the keys in `key-vector`.

```scheme
(with-continuation-mark
  'key "val"
  (with-continuation-mark
    'other "also"
    (values
      (with-continuation-mark
        'key "val2"
        (let loop ([iter (continuation-marks->iterator
                         (current-continuation-marks)
                         '#(key other))])
          (let-values ([(vec iter) (iter)])
            (if vec
                (cons vec (loop iter))
                '(())))))) ; => ("val2" #f) ("val" "also")
```
6.4. Engines

Engines are a high-level process abstraction supporting timed preemption [15, 24]. Engines may be used to simulate multiprocessing, implement operating system kernels, and perform nondeterministic computations.
An engine is created by passing a thunk (no argument procedure) to \texttt{make-engine}. The body of the thunk is the computation to be performed by the engine. An engine itself is a procedure of three arguments:

\begin{itemize}
  \item \textit{ticks}: a positive integer that specifies the amount of \textit{fuel} to be given to the engine. An engine executes until this fuel runs out or until its computation finishes.
  \item \textit{complete}: a procedure of one or more arguments that specifies what to do if the computation finishes. Its arguments are the amount of fuel left over and the values produced by the computation.
  \item \textit{expire}: a procedure of one argument that specifies what to do if the fuel runs out before the computation finishes. Its argument is a new engine capable of continuing the computation from the point of interruption.
\end{itemize}

When an engine is applied to its arguments, it sets up a timer to fire in \textit{ticks} time units. (See \texttt{set-timer} on page \pageref{set-timer}.) If the engine computation completes before the timer expires, the system invokes \textit{complete}, passing it the number of \textit{ticks} left over and the values produced by the computation. If, on the other hand, the timer goes off before the engine computation completes, the system creates a new engine from the continuation of the interrupted computation and passes this engine to \textit{expire}. \textit{complete} and \textit{expire} are invoked in the continuation of the engine invocation.

An implementation of engines is given in Section 12.11 of \textit{The Scheme Programming Language, 4th Edition}.

Do not use the timer interrupt (see \texttt{set-timer}) and engines at the same time, since engines are implemented in terms of the timer.

The following example creates an engine from a trivial computation, 3, and gives the engine 10 ticks.

\begin{verbatim}
(define eng
  (make-engine
    (lambda () 3)))

(eng 10
  (lambda (ticks value) value)
  (lambda (x) x)) \Rightarrow 3
\end{verbatim}

It is often useful to pass \texttt{list} as the \textit{complete} procedure to an engine, causing an engine that completes to return a list whose first element is the ticks remaining and whose remaining elements are the values returned by the computation.

\begin{verbatim}
(define eng
  (make-engine
    (lambda () 3)))
\end{verbatim}
In the example above, the value is 3 and there are 9 ticks left over, i.e., it takes one unit of fuel to evaluate 3. (The fuel amounts given here are for illustration only. Your mileage may vary.)

Typically, the engine computation does not finish in one try. The following example displays the use of an engine to compute the 10th Fibonacci number in steps.

```
(define fibonacci
  (lambda (n)
    (let fib ([i n])
      (cond
        [(= i 0) 0]
        [(= i 1) 1]
        [else (+ (fib (- i 1))
                (fib (- i 2)))]))))

(define eng
  (make-engine
    (lambda ()
      (fibonacci 10))))
```

```
(eng 50
  list
  (lambda (new-eng)
    (set! eng new-eng)
    "expired")) ⇒ "expired"
```

```
(eng 50
  list
  (lambda (new-eng)
    (set! eng new-eng)
    "expired")) ⇒ "expired"
```

```
(eng 50
  list
  (lambda (new-eng)
    (set! eng new-eng)
    "expired")) ⇒ "expired"
```

```
(eng 50
  list
  (lambda (new-eng)
    (set! eng new-eng)
    "expired")) ⇒ (21 55)
```

Each time the engine’s fuel runs out, the expire procedure assigns eng to the new engine. The entire computation requires four blocks of 50 ticks to complete; of the last 50 it uses all but 21. Thus, the total amount of fuel used is 179 ticks. This leads to the following
procedure, *mileage*, which “times” a computation using engines:

```scheme
(define mileage
  (lambda (thunk)
    (let loop ([eng (make-engine thunk)] [total-ticks 0])
      (eng 50
        (lambda (ticks . values)
          (+ total-ticks (- 50 ticks)))
        (lambda (new-eng)
          (loop new-eng
            (+ total-ticks 50))))))

(mileage (lambda () (fibonacci 10))) ⇒ 179
```

The choice of 50 for the number of ticks to use each time is arbitrary, of course. It might make more sense to pass a much larger number, say 10000, in order to reduce the number of times the computation is interrupted.

The next procedure is similar to *mileage*, but it returns a list of engines, one for each tick it takes to complete the computation. Each of the engines in the list represents a “snapshot” of the computation, analogous to a single frame of a moving picture. *snapshot* might be useful for “single stepping” a computation.

```scheme
(define snapshot
  (lambda (thunk)
    (let again ([eng (make-engine thunk)])
      (cons eng
        (eng 1 (lambda (t . v) '() again))))))
```

The recursion embedded in this procedure is rather strange. The complete procedure performs the base case, returning the empty list, and the expire procedure performs the recursion.

The next procedure, *round-robin*, could be the basis for a simple time-sharing operating system. *round-robin* maintains a queue of processes (a list of engines), cycling through the queue in a *round-robin* fashion, allowing each process to run for a set amount of time. *round-robin* returns a list of the values returned by the engine computations in the order that the computations complete. Each computation is assumed to produce exactly one value.

```scheme
(define round-robin
  (lambda (engs)
    (if (null? engs)
      ()
      ((car engs)
       1
       (lambda (ticks value)
         (cons value (round-robin (cdr engs))))
       (lambda (eng)
         (round-robin
           (append (cdr engs) (list eng))))))))
```
Since the amount of fuel supplied each time, one tick, is constant, the effect of \textit{round-robin} is to return a list of the values sorted from the quickest to complete to the slowest to complete. Thus, when we call \textit{round-robin} on a list of engines, each computing one of the Fibonacci numbers, the output list is sorted with the earlier Fibonacci numbers first, regardless of the order of the input list.

\begin{verbatim}
(round-robin
  (map (lambda (x)
    (make-engine
      (lambda ()
        (fibonacci x))))
  '(4 5 2 8 3 7 6 2))) ⇒ (1 1 2 3 5 8 13 21)
\end{verbatim}

More interesting things can happen if the amount of fuel varies each time through the loop. In this case, the computation would be nondeterministic, i.e., the results would vary from call to call.

The following syntactic form, \textit{por} (parallel-or), returns the first of its expressions to complete with a true value. \textit{por} is implemented with the procedure \textit{first-true}, which is similar to \textit{round-robin} but quits when any of the engines completes with a true value. If all of the engines complete, but none with a true value, \textit{first-true} (and hence \textit{por}) returns \texttt{#f}. Also, although \textit{first-true} passes a fixed amount of fuel to each engine, it chooses the next engine to run at random, and is thus nondeterministic.

\begin{verbatim}
(define-syntax por
  (syntax-rules ()
    [(_ x ...) (first-true (list (make-engine (lambda () x)) ...))])

(define first-true
  (let ([pick (lambda (ls)
                (list-ref ls (random (length ls))))]
        (lambda (engs)
          (if (null? engs)
              #f
              (let ([eng (pick engs)])
                (eng 1
                  (lambda (ticks value)
                    (or value
                      (first-true
                        (remq eng engs)))
                      (lambda (new-eng)
                        (first-true
                          (cons new-eng
                            (remq eng engs))))))))))
\end{verbatim}

The list of engines is maintained with \texttt{pick}, which randomly chooses an element of the list, and \texttt{remq}, which removes the chosen engine from the list. Since \texttt{por} is nondeterministic,
subsequent uses with the same expressions may not return the same values.

\[(\text{por} \ 1 \ 2 \ 3) \Rightarrow 2\]
\[(\text{por} \ 1 \ 2 \ 3) \Rightarrow 3\]
\[(\text{por} \ 1 \ 2 \ 3) \Rightarrow 2\]
\[(\text{por} \ 1 \ 2 \ 3) \Rightarrow 1\]

Furthermore, even if one of the expressions is an infinite loop, \text{por} still finishes as long as one of the other expressions completes and returns a true value.

\[(\text{por} \ (\text{let} \ \text{loop} () \ (\text{loop})) \ 2) \Rightarrow 2\]

With \text{engine-return} and \text{engine-block}, it is possible to terminate an engine explicitly. \text{engine-return} causes the engine to complete, as if the computation had finished. Its arguments are passed to the \text{complete} procedure along with the number of ticks remaining. It is essentially a nonlocal exit from the engine. Similarly, \text{engine-block} causes the engine to expire, as if the timer had run out. A new engine is made from the continuation of the call to \text{engine-block} and passed to the \text{expire} procedure.

\begin{verbatim}
(engine-block)
returns: does not return
libraries: (chezscheme)

This causes a running engine to stop, create a new engine capable of continuing the computation, and pass the new engine to the original engine's third argument (the expire procedure). Any remaining fuel is forfeited.

(define eng
  (make-engine
    (lambda ()
      (engine-block)
      "completed")))

(eng 100
  (lambda (ticks value) value)
  (lambda (x)
    (set! eng x)
    "expired") \Rightarrow "expired"

(eng 100
  (lambda (ticks value) value)
  (lambda (x)
    (set! eng x)
    "expired") \Rightarrow "completed"
\end{verbatim}
This causes a running engine to stop and pass control to the engine’s `complete` argument. The first argument passed to the complete procedure is the amount of fuel remaining, as usual, and the remaining arguments are the objects `obj ...` passed to `engine-return`.

```scheme
(define eng
  (make-engine
   (lambda ()
     (reverse (engine-return 'a 'b 'c))))))

(eng 100
  (lambda (ticks . values) values)
  (lambda (new-eng) "expired") ⇒ (a b c)
```
7. Operations on Objects

This chapter describes operations specific to Chez Scheme on nonnumeric objects, including standard objects such as pairs and numbers and Chez Scheme extensions such as boxes and records. Chapter 6 describes operations on numbers. See Chapter 6 of The Scheme Programming Language, 4th Edition or the Revised 6 Report on Scheme for a description of standard operations on objects.

7.1. Missing R6RS Type Predicates

\[ \text{(enum-set? } \ obj \text{)} \]

returns: \#t if \( \text{obj} \) is an enum set, \#f otherwise

libraries: (chezscheme)

This predicate is not defined by the Revised 6 Report, but should be.

\[ \text{(record-constructor-descriptor? } \ obj \text{)} \]

returns: \#t if \( \text{obj} \) is a record constructor descriptor, \#f otherwise

libraries: (chezscheme)

This predicate is not defined by the Revised 6 Report, but should be.

7.2. Pairs and Lists

\[ \text{(atom? } \ obj \text{)} \]

returns: \#t if \( \text{obj} \) is not a pair, \#f otherwise

libraries: (chezscheme)

atom? is equivalent to \((\text{lambda} \ (x) \ \text{(not} \ (\text{pair?} \ x)))\).

\[(\text{atom? } \ (\text{a} \ \text{b} \ \text{c})) \Rightarrow \ #f\]
\[(\text{atom? } \ (\text{3} \ . \ \text{4})) \Rightarrow \ #f\]
\[(\text{atom? } \ (\text{()})) \Rightarrow \ #t\]
\[(\text{atom? } \ 3) \Rightarrow \ #t\]
7. Operations on Objects

(list-head list n)  
procedure
returns: a list of the first n elements of list
libraries: (chezscheme)

n must be an exact nonnegative integer less than or equal to the length of list.

list-head and the standard Scheme procedure list-tail may be used together to split a list into two separate lists. While list-tail performs no allocation but instead returns a sublist of the original list, list-head always returns a copy of the first portion of the list.

list-head may be defined as follows.

(define list-head
  (lambda (ls n)
    (if (= n 0)
        ()
      (cons (car ls) (list-head (cdr ls) (- n 1)))))

(list-head '(a b c) 0)  ⇒  ()
(list-head '(a b c) 2)  ⇒  (a b)
(list-head '(a b c) 3)  ⇒  (a b c)
(list-head '(a b c . d) 2)  ⇒  (a b)
(list-head '(a b c . d) 3)  ⇒  (a b c)
(list-head '#1=(a . #1#) 5)  ⇒  (a a a a a)

(last-pair list)  
procedure
returns: the last pair of a list
libraries: (chezscheme)

list must not be empty. last-pair returns the last pair (not the last element) of list. list may be an improper list, in which case the last pair is the pair containing the last element and the terminating object.

(last-pair '(a b c d))  ⇒  (d)
(last-pair '(a b c . d))  ⇒  (c . d)

(list-assuming-immutable? v)  
procedure
returns: a boolean
libraries: (chezscheme)

Like list?, but on the assumption that any pairs traversed while computing the result are never mutated further, the result is produced in amortized constant time.

(list-assuming-immutable? '(a b c d))  ⇒  #t
(list-assuming-immutable? '(a b c . d))  ⇒  #f
(list-copy list)  procedure
returns: a copy of list
libraries: (chezscheme)

list-copy returns a list equal? to list, using new pairs to reform the top-level list structure.

(list-copy '(a b c)) ⇒ (a b c)
(let ([ls '(a b c)])
  (equal? ls (list-copy ls))) ⇒ #t
(let ([ls '(a b c)])
  (let ([ls-copy (list-copy ls)]
        (or (eq? ls-copy ls)
            (eq? (cdr ls-copy) (cdr ls))
            (eq? (cddr ls-copy) (cddr ls)))))) ⇒ #f

(list* obj ... final-obj)  procedure
returns: a list of obj ... terminated by final-obj
libraries: (chezscheme)

list* is identical to the Revised⁶ Report cons*.

(make-list n)  procedure
(make-list n obj)  procedure
returns: a list of n objs
libraries: (chezscheme)

n must be a nonnegative integer. If obj is omitted, the elements of the list are unspecified.

(make-list 0 '()) ⇒ ()
(make-list 3 0) ⇒ (0 0 0)
(make-list 2 "hi") ⇒ ("hi" "hi")

(iota n)  procedure
returns: a list of integers from 0 (inclusive) to n (exclusive)
libraries: (chezscheme)

n must be an exact nonnegative integer.

(iota 0) ⇒ ()
(iota 5) ⇒ (0 1 2 3 4)

(enumerate ls)  procedure
returns: a list of integers from 0 (inclusive) to the length of ls (exclusive)
libraries: (chezscheme)
(enumerate '()) ⇒ ()
(enumerate '(a b c)) ⇒ (0 1 2)
(let ([ls '(a b c)])
  (map cons ls (enumerate ls))) ⇒ ((a . 0) (b . 1) (c . 2))

(remq! obj list) procedure
(remv! obj list) procedure
(remove! obj list) procedure
returns: a list containing the elements of list with all occurrences of obj removed
libraries: (chezscheme)

These procedures are similar to the Revised\textsuperscript{6} Report remq, remv, and remove procedures, except remq!, remv! and remove! use pairs from the input list to build the output list. They perform less allocation but are not necessarily faster than their nondestructive counterparts. Their use can easily lead to confusing or incorrect results if used indiscriminately.

(remq! 'a '(a b a c a d)) ⇒ (b c d)
(remv! #\a '#(\a #\b #\c)) ⇒ (#\b #\c)
(remove! '(c)'((a) (b) (c))) ⇒ ((a) (b))

(substq new old tree) procedure
(substv new old tree) procedure
(subst new old tree) procedure
(substq! new old tree) procedure
(substv! new old tree) procedure
(subst! new old tree) procedure
returns: a tree with new substituted for occurrences of old in tree
libraries: (chezscheme)

These procedures traverse tree, replacing all objects equivalent to the object old with the object new.

The equivalence test for substq and substq! is eq?, for substv and substv! is eqv?, and for subst and subst! is equal?.

substq!, substv!, and subst! perform the substitutions destructively. They perform less allocation but are not necessarily faster than their nondestructive counterparts. Their use can easily lead to confusing or incorrect results if used indiscriminately.

(substq 'a 'b '((b c) b a)) ⇒ ((a c) a a)
(substv 2 1 '((1 . 2) (1 . 4) . 1)) ⇒ ((2 . 2) (2 . 4) . 2)
(subst 'a
  '(a . b)
  '((a . b) (c a . b) . c)) ⇒ (a (c . a) . c)
(let ([tr ’((b c) b a)])
  (substq! ’a ’b tr)
  tr) ⇒ ((a c) a a)

(reverse! list) procedure
returns: a list containing the elements of list in reverse order
libraries: (chezscheme)

reverse! destructively reverses list by reversing its links. Using reverse! in place of reverse reduces allocation but is not necessarily faster than reverse. Its use can easily lead to confusing or incorrect results if used indiscriminately.

(reverse! ’()) ⇒ ()
(reverse! ’(a b c)) ⇒ (c b a)

(let ([x ’(a b c)])
  (reverse! x)
  x) ⇒ (a)

(let ([x ’(a b c)])
  (set! x (reverse! x))
  x) ⇒ (c b a)

(append! list ...) procedure
returns: the concatenation of the input lists
libraries: (chezscheme)

Like append, append! returns a new list consisting of the elements of the first list followed by the elements of the second list, the elements of the third list, and so on. Unlike append, append! reuses the pairs in all of the arguments in forming the new list. That is, the last cdr of each list argument but the last is changed to point to the next list argument. If any argument but the last is the empty list, it is essentially ignored. The final argument (which need not be a list) is not altered.

append! performs less allocation than append but is not necessarily faster. Its use can easily lead to confusing or incorrect results if used indiscriminately.

(append! ’(a b) ’(c d)) ⇒ (a b c d)

(let ([x ’(a b)])
  (append! x ’(c d))
  x) ⇒ (a b c d)

7.3. Characters

Chez Scheme extends the syntax of characters in two ways. First, a \#\ prefix followed by exactly three octal digits is read as a character whose numeric code is the octal value
of the three digits, e.g., \#\044 is read as #\$. Second, it recognizes several nonstandard named characters: #\rubout (which is the same as #\delete), #\bel (which is the same as #\alarm), #\vt (which is the same as #\vtab), #\nel (the Unicode NEL character), and #\ls (the Unicode LS character). The set of nonstandard character names may be changed via the procedure char-name (page 9.14).

These extensions are disabled in an input stream after #!r6rs has been seen by the reader, unless #!chezscheme has been seen more recently.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(char=? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char&lt;? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char&gt;? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char&lt;=? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char&gt;=? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char-ci=? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char-ci&gt;? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char-ci&lt;? char1 char2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(char-ci&gt;=? char1 char2 ...)</td>
<td>procedure</td>
</tr>
</tbody>
</table>

returns: #t if the relation holds, #f otherwise

libraries: (chezscheme)

These predicates are identical to the Revised\(^6\) Report counterparts, except they are extended to accept one or more rather than two or more arguments. When passed one argument, each of these predicates returns #t.

- (char>? #\a) ⇒ #t
- (char<? #\a) ⇒ #t
- (char-ci=? #\a) ⇒ #t

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(char-ci=? char1 char2 ...)</td>
<td>procedure</td>
</tr>
</tbody>
</table>

returns: the integer difference between char1 and char2

libraries: (chezscheme)

char- subtracts the integer value of char2 from the integer value of char1 and returns the difference. The following examples assume that the integer representation is the ASCII code for the character.

- (char- #\f #\e) ⇒ 1

(define digit-value
 ; returns the digit value of the base-r digit c, or #f if c
 ; is not a valid digit
 (lambda (c r)
   (let ([v (cond
         [(char<=? #\0 c #\9) (char- c #\0)]
         [(char<=? #\A c #\Z) (char- c #\7)]
         [(char<=? #\a c #\z) (char- c #\W)]])
     v)))
[else 36]])
       (and (fx< v r v)))
(digit-value #\8 10) ⇒ 8
(digit-value #\z 10) ⇒ #f
(digit-value #\z 36) ⇒ 35

char- might be defined as follows.

(define char-
   (lambda (c1 c2)
       (- (char->integer c1) (char->integer c2))))

(char-grapheme-step char state)

returns: two values: a boolean indicating whether a cluster terminated and a new state

libraries: (chezscheme)

char must be a character, and state must be a fixnum.

char-grapheme-step encodes a state machine for Unicode’s grapheme specification on a
sequence of code points. It accepts a character for the next code point in a sequence, and
it returns two values: whether a (single) grapheme cluster has terminated since the most
recently reported termination (or the start of the stream), and a new state to be used with
char-grapheme-step and the next character.

A state is represented by a fixnum. A value of 0 for state represents the initial state or
a state where no characters are pending toward a new boundary. Thus, if a sequence of
characters is exhausted and state is not 0, then the end of the stream creates one last
grapheme boundary.

char-grapheme-step will produce a result for any fixnum state, but the meaning of a non-
0 state is specified only in that providing such a state produced by char-grapheme-step
in another call to char-grapheme-step continues detecting grapheme boundaries in the
sequence.

(char-grapheme-break-property char)

returns: a symbol

libraries: (chezscheme)

char-grapheme-break-property reports the grapheme-break property of char, one of
Other, CR, LF, Control, Extend, ZWJ, Regional_Indicator, Prepend, SpacingMark, L, V,
T, LV, or LVT. This function is used in the implementation of char-grapheme-step.

(char-grapheme-break-property #\a) ⇒ Other
(char-grapheme-break-property #\x300) ⇒ Extend
7. Operations on Objects

**(char-extended-pictographic? char)**

**procedure**

returns: a boolean

libraries: (chezscheme)

`char-extended-pictographic?` reports whether `char` has the Unicode Extended_Pictographic property. This function is used in the implementation of `char-grapheme-step`.

```scheme
(char-extended-pictographic? #\a) ⇒ #f
(char-extended-pictographic? #\xA9) ⇒ #t
```

7.4. Strings

*Chez Scheme* extends the standard string syntax with two character escapes: `\'`, which produces the single quote character, and `\nnn`, i.e., backslash followed by 3 octal digits, which produces the character equivalent of the octal value of the 3 digits. These extensions are disabled in an input stream after `#!r6rs` has been seen by the reader, unless `#!chezscheme` has been seen more recently.

All strings are mutable by default, including constants. A program can create immutable strings via `string->immutable-string` or `string-append-immutable`. Any attempt to modify an immutable string causes an exception to be raised.

The length and indices of a string in *Chez Scheme* are always fixnums.

```scheme
(string=? string1 string2 string3 ...)
(string<? string1 string2 string3 ...)
(string>=? string1 string2 string3 ...)
(string-ci=? string1 string2 string3 ...)
(string-ci<? string1 string2 string3 ...)
(string-ci>=? string1 string2 string3 ...)
```

returns: #t if the relation holds, #f otherwise

libraries: (chezscheme)

These predicates are identical to the Revised⁶ Report counterparts, except they are extended to accept one or more rather than two or more arguments. When passed one argument, each of these predicates returns #t.

```scheme
(string>? "a") ⇒ #t
(string<? "a") ⇒ #t
(string-ci=? "a") ⇒ #t
```
7.4. Strings

(string-copy! src src-start dst dst-start n)  
procedure
returns: unspecified
libraries: (chezscheme)

src and dst must be strings, and dst must be mutable. src-start, dst-start, and n must be exact nonnegative integers. The sum of src-start and n must not exceed the length of src, and the sum of dst-start and n must not exceed the length of dst.

string-copy! overwrites the n bytes of dst starting at dst-start with the n bytes of dst starting at src-start. This works even if dst is the same string as src and the source and destination locations overlap. That is, the destination is filled with the characters that appeared at the source before the operation began.

(define s1 "to boldly go")
(define s2 (make-string 10 #\-))

(string-copy! s1 3 s2 1 3)
s2 ⇒ "-bol------"

(string-copy! s1 7 s2 4 2)
s2 ⇒ "-bolly----"

(string-copy! s2 2 s2 5 4)
s2 ⇒ "-bollolly-"

(substring-fill! string start end char)  
procedure
returns: unspecified
libraries: (chezscheme)

string must be mutable. The characters of string from start (inclusive) to end (exclusive) are set to char. start and end must be nonnegative integers; start must be strictly less than the length of string, while end may be less than or equal to the length of string. If end ≤ start, the string is left unchanged.

(let ([str (string-copy "a typo typo")])
  (substring-fill! str 2 6 #\X)
  str) ⇒ "a XXXX typo"

(string-truncate! string n)  
procedure
returns: string or the empty string
libraries: (chezscheme)

string must be mutable. n must be an exact nonnegative fixnum not greater than the length of string. If n is zero, string-truncate! returns the empty string. Otherwise, string-truncate! destructively truncates string to its first n characters and returns string.
(define s (make-string 7 #\$))
(string-truncate! s 0) ⇒ ""
s ⇒ "$$$$$$$
(string-truncate! s 3) ⇒ "$$"
s ⇒ "$$

(mutable-string? obj) procedure
returns: #t if obj is a mutable string, #f otherwise

(immutable-string? obj) procedure
returns: #t if obj is an immutable string, #f otherwise

libraries: (chezscheme)

(mutable-string? (string #\a #\b #\c)) ⇒ #t
(mutable-string? (string->immutable-string "abc")) ⇒ #f
(immutable-string? (string #\a #\b #\c)) ⇒ #f
(immutable-string? (string->immutable-string "abc")) ⇒ #t
(immutable-string? (cons 3 4)) ⇒ #f

(string->immutable-string string) procedure
returns: an immutable string equal to string
libraries: (chezscheme)

The result is string itself if string is immutable; otherwise, the result is an immutable string
with the same content as string.

(define s (string->immutable-string (string #\x #\y #\z)))
(string-set! s 0 #\a) ⇒ exception: not mutable

(string-append-immutable string ...) procedure
returns: an immutable string that appends the argument strings
libraries: (chezscheme)

Like string-append, but produces an immutable string.

(string-grapheme-span string start) procedure
(string-grapheme-span string start end) procedure
returns: the number of characters in a grapheme cluster at the given start
libraries: (chezscheme)

start and end must indicate a valid range in the string as for substring, where the length
of the string is used if end is not supplied.

The result is the number of characters (i.e., code points) in the string that form a Unicode
grapheme cluster starting at start, assuming that start is the start of a grapheme cluster
and extending no further than the character before end. The result is 0 if start equals end.
7.5. Vectors

(string-grapheme-span (string #\a) 0) ⇒ 1
(string-grapheme-span (string #\a #\x300) 0) ⇒ 2
(string-grapheme-span (string #\a #\x300 #\a) 0) ⇒ 2
(string-grapheme-span (string #\a #\x300 #\a) 0 1) ⇒ 1

(string-grapheme-count string) procedure
(string-grapheme-count string start) procedure
(string-grapheme-count string start end) procedure
returns: the number of Unicode grapheme clusters (see below)
libraries: (chezscheme)

start and end must indicate a valid range in the string as for substring, where 0 is used if start is not provided, and the length of the string is used if end is not supplied.
The result is the number of Unicode grapheme clusters in the substring of string selected by start and end.

(string-grapheme-count (string #\a) 0) ⇒ 1
(string-grapheme-count (string #\a #\x300) 0) ⇒ 1
(string-grapheme-count (string #\a #\x300 #\a) 0) ⇒ 2
(string-grapheme-count (string #\a #\x300 #\a) 0 1) ⇒ 1

7.5. Vectors

Chez Scheme extends the syntax of vectors to allow the length of the vector to be specified between the # and open parenthesis, e.g., #3(a b c). If fewer elements are supplied in the syntax than the specified length, each element after the last printed element is the same as the last printed element. This extension is disabled in an input stream after #!r6rs has been seen by the reader, unless #!chezscheme has been seen more recently.
The length and indices of a vector in Chez Scheme are always fixnums.
All vectors are mutable by default, including constants. A program can create immutable vectors via vector->immutable-vector. Any attempt to modify an immutable vector causes an exception to be raised.

(vector-copy vector) procedure
returns: a copy of vector
libraries: (chezscheme)

vector-copy creates a new vector of the same length and contents as vector. The elements themselves are not copied.

(vector-copy '#(a b c)) ⇒ #(a b c)
(let ([v '#(a b c)])
  (eq? v (vector-copy v))) ⇒ #f
7. Operations on Objects

(vector-set-fixnum! vector n fixnum)  
procedure
returns: unspecified
libraries: (chezscheme)

vector must be mutable. vector-set-fixnum! changes the n\textsuperscript{th} element of vector to fixnum. n must be an exact nonnegative integer strictly less than the length of vector.

It is faster to store a fixnum than an arbitrary value, since for arbitrary values, the system has to record potential assignments from older to younger objects to support generational garbage collection. Care must be taken to ensure that the argument is indeed a fixnum, however; otherwise, the collector may not properly track the assignment. The primitive performs a fixnum check on the argument except at optimization level 3.

See also the description of fixnum-only vectors (fxvectors) below.

(let ([v (vector 1 2 3 4 5)])
  (vector-set-fixnum! v 2 73)
  v)  ⇒  #(1 2 73 4 5)

(vector-cas! vector n old-obj new-obj)  
procedure
returns: #t if vector is changed, #f otherwise
libraries: (chezscheme)

vector must be mutable. vector-cas! atomically changes the n\textsuperscript{th} element of vector to new-obj if the replaced n\textsuperscript{th} element is eq? to old-obj. If the n\textsuperscript{th} element of vector that would be replaced is not eq? to old-obj, then vector is unchanged.

On an architecture with a weak memory model, vector-cas! can spuriously fail, leaving vector unchanged and returning #f even if the current value of element n is old-obj. On success, no memory ordering is implied, which means that memory-order-acquire and/or memory-order-release may be needed to complete an intended synchronization.

(define v (vector 'old0 'old1 'old2))
(vector-cas! v 1 'old1 'new1)  ⇒  #t, assuming no spurious failure
(vector-ref v 1)  ⇒  'new1
(vector-cas! v 2 'old1 'new2)  ⇒  #f
(vector-ref v 2)  ⇒  'old2

(mutable-vector? obj)  
procedure
returns: #t if obj is a mutable vector, #f otherwise

(immutable-vector? obj)  
procedure
returns: #t if obj is an immutable vector, #f otherwise
libraries: (chezscheme)

(mutable-vector? (vector 1 2 3))  ⇒  #t
(mutable-vector? (vector->immutable-vector (vector 1 2 3)))  ⇒  #f
(immutable-vector? (vector 1 2 3))  ⇒  #f
(immutable-vector? (vector->immutable-vector (vector 1 2 3)))  ⇒  #t
(immutable-vector? (cons 3 4))  ⇒  #f
7.6. Fixnum-Only Vectors

**vector->immutable-vector** ~Procedure~

returns: an immutable vector equal to ~vector~

libraries: (chezscheme)

The result is ~vector~ itself if ~vector~ is immutable; otherwise, the result is an immutable vector with the same content as ~vector~.

```
(define v (vector->immutable-vector (vector 1 2 3)))
(vector-set! v 0 0) ⇒ exception: not mutable
```

自评估向量

thread parameter

libraries: (chezscheme)

The default value of this parameter is ~#f~, meaning that vector literals must be quoted, as required by the Revised^6~ Report. Setting self-evaluating-vectors to a true value may be useful to provide compatibility with R^7 RS, as the latter states that vectors are self-evaluating.

```
#(a b c) ⇒ exception: invalid syntax
(self-evaluating-vectors #t)
#(a b c) ⇒ #(a b c)
```

7.6. Fixnum-Only Vectors

Fixnum-only vectors, or “fxvectors,” are like vectors but contain only fixnums. Fxvectors are written with the #vfx prefix in place of the # prefix for vectors, e.g., #vfx(1 2 3) or #10vfx(2). The fxvector syntax is disabled in an input stream after #!r6rs has been seen by the reader, unless #!chezscheme has been seen more recently.

The length and indices of an fxvector are always fixnums.

Updating an fxvector is generally less expensive than updating a vector, since for vectors, the system records potential assignments from older to younger objects to support generational garbage collection. The storage management system also takes advantage of the fact that fxvectors contain no pointers to place them in an area of memory that does not have to be traced during collection.

See also vector-set-fixnum! above.

**fxvector?** ~Procedure~

returns: ~#t~ if ~obj~ is an fxvector, ~#f~ otherwise

libraries: (chezscheme)

```
(fxvector? #vfx()) ⇒ #t
(fxvector? #vfx(1 2 3)) ⇒ #t
(fxvector? (fxvector 1 2 3)) ⇒ #t
(fxvector? '#(a b c)) ⇒ #f
```
7. Operations on Objects

(fxvector? '(a b c)) ⇒ #f
(fxvector? "abc") ⇒ #f

(fxvector fixnum ...) procedure
returns: an fxvector of the fixnums fixnum ...
libraries: (chezscheme)

(fxvector) ⇒ #vfx()
(fxvector 1 3 5) ⇒ #vfx(1 3 5)

(make-fxvector n) procedure
(make-fxvector n fixnum) procedure
returns: an fxvector of length n
libraries: (chezscheme)

n must be a fixnum. If fixnum is supplied, each element of the fxvector is initialized to fixnum; otherwise, the elements are unspecified.

(make-fxvector 0) ⇒ #vfx()
(make-fxvector 0 7) ⇒ #vfx()
(make-fxvector 5 7) ⇒ #vfx(7 7 7 7 7)

(fxvector-length fxvector) procedure
returns: the number of elements in fxvector
libraries: (chezscheme)

(fxvector-length #vfx()) ⇒ 0
(fxvector-length #vfx(1 2 3)) ⇒ 3
(fxvector-length #v10vfx(1 2 3)) ⇒ 10
(fxvector-length (fxvector 1 2 3 4)) ⇒ 4
(fxvector-length (make-fxvector 300)) ⇒ 300

(fxvector-ref fxvector n) procedure
returns: the nth element (zero-based) of fxvector
libraries: (chezscheme)

n must be a nonnegative fixnum strictly less than the length of fxvector.

(fxvector-ref #vfx(-1 2 4 7) 0) ⇒ -1
(fxvector-ref #vfx(-1 2 4 7) 1) ⇒ 2
(fxvector-ref #vfx(-1 2 4 7) 3) ⇒ 7
7.6. Fixnum-Only Vectors

**(fxvector-set! fxvector n fixnum)**

**procedure**

returns: unspecified

libraries: (chezscheme)

\( n \) must be a nonnegative fixnum strictly less than the length of \( fxvector \). \( fxvector-set! \) changes the \( n \)th element of \( fxvector \) to \( fixnum \).

(\( \text{let } ([v \text{ fxvector 1 2 3 4 5}]) \)
  (\( \text{fxvector-set! } v \ 2 \text{ (fx- (fxvector-ref } v \text{ 2})} \))
  \( v \)) \( \Rightarrow \) \#vfx(1 2 -3 4 5)

**(fxvector-fill! fxvector fixnum)**

**procedure**

returns: unspecified

libraries: (chezscheme)

\( fxvector-fill! \) replaces each element of \( fxvector \) with \( fixnum \).

(\( \text{let } ([v \text{ fxvector 1 2 3}]) \)
  (\( \text{fxvector-fill! } v \ 0 \))
  \( v \)) \( \Rightarrow \) \#vfx(0 0 0)

**(fxvector->list fxvector)**

**procedure**

returns: a list of the elements of \( fxvector \)

libraries: (chezscheme)

\( \text{(fxvector->list } (\text{fxvector})) \Rightarrow () \)
\( \text{(fxvector->list } \text{#vfx(7 5 2)}) \Rightarrow (7 5 2) \)

(\( \text{let } ([v \text{ #vfx(1 2 3 4 5}]) \)
  (\( \text{apply fx* (fxvector->list } v))\)) \Rightarrow 120

**(list->fxvector list)**

**procedure**

returns: an fxvector of the elements of \( list \)

libraries: (chezscheme)

\( list \) must consist entirely of fixnums.

\( \text{(list->fxvector } '()) \Rightarrow \text{#vfx()} \)
\( \text{(list->fxvector } '\text{(3 5 7)}) \Rightarrow \text{#vfx(3 5 7}) \)

(\( \text{let } ([v \text{ #vfx(1 2 3 4 5})]) \)
  (\( \text{let } ([ls \text{ (fxvector->list } v))]) \)
  (\( \text{list->fxvector } \text{(map fx* } ls \text{ ls)})\)) \Rightarrow \text{#vfx(1 4 9 16 25})
7. Operations on Objects

- **fxvector-copy** function:
  - Returns: A copy of the input `fxvector`.
  - Libraries: (chezscheme)

  `fxvector-copy` creates a new `fxvector` with the same length and contents as the input `fxvector`.

  ```scheme
  (fxvector-copy #vfx(3 4 5)) ⇒ #vfx(3 4 5)
  (let ([v #vfx(3 4 5)])
    (eq? v (fxvector-copy v))) ⇒ #f
  ```

7.7. Flonum-Only Vectors

Flonum-only vectors, or “flvectors,” are like vectors but contain only flonums. Flvectors are written with the `#vfl` prefix in place of the `#` prefix for vectors, e.g., `#vfl(1.0 2.0 3.0)` or `#10vfl(2.0)`. The flvector syntax is disabled in an input stream after `#!r6rs` has been seen by the reader, unless `#!chezscheme` has been seen more recently.

The length and indices of an flvector are always fixnums.

Updating an flvector is generally less expensive than updating a vector, since for vectors, the system records potential assignments from older to younger objects to support generational garbage collection. An flvector stores a flonum's representation directly, instead of a reference to a flonum, so flonum identity is fresh when it is extracted from an flvector.

The storage management system also takes advantage of the fact that flvectors contain no pointers to place them in an area of memory that does not have to be traced during collection.

- **flvector?** function:
  - Returns: `#t` if `obj` is an flvector, `#f` otherwise.
  - Libraries: (chezscheme)

  ```scheme
  (flvector? #vfl()) ⇒ #t
  (flvector? #vfl(1.0 2.0 3.0)) ⇒ #t
  (flvector? (flvector 1.0 2.0 3.0)) ⇒ #t
  (flvector? '(a b c)) ⇒ #f
  (flvector? "abc") ⇒ #f
  ```

- **flvector** function:
  - Returns: An flvector of the flonums `flonum` ...
  - Libraries: (chezscheme)

  ```scheme
  (flvector) ⇒ #vfl()
  (flvector 1.0 3.0 5.0) ⇒ #vfl(1.0 3.0 5.0)
  ```
7.7. Flonum-Only Vectors

\begin{itemize}
    \item \texttt{(make-flvector n)} \texttt{procedure} \texttt{returns: an flvector of length n}
    \item \texttt{(make-flvector n flonum)} \texttt{procedure} \texttt{libraries: (chezscheme)}
\end{itemize}

\( n \) must be a fixnum. If \texttt{flonum} is supplied, each element of the flvector is initialized to \texttt{flonum}; otherwise, the elements are unspecified.

\begin{itemize}
    \item \texttt{(make-flvector 0)} \Rightarrow \texttt{#vfl()}
    \item \texttt{(make-flvector 0 7.0)} \Rightarrow \texttt{#vfl()}
    \item \texttt{(make-flvector 5 7.0)} \Rightarrow \texttt{#vfl(7.0 7.0 7.0 7.0 7.0)}
\end{itemize}

\begin{itemize}
    \item \texttt{(flvector-length flvector)} \texttt{procedure} \texttt{returns: the number of elements in flvector}
    \item \texttt{libraries: (chezscheme)}
\end{itemize}

\begin{itemize}
    \item \texttt{(flvector-length #vfl())} \Rightarrow 0
    \item \texttt{(flvector-length #vfl(1.0 2.0 3.0))} \Rightarrow 3
    \item \texttt{(flvector-length #10vfl(1.0 2.0 3.0))} \Rightarrow 10
    \item \texttt{(flvector-length (flvector 1.0 2.0 3.0 4.0))} \Rightarrow 4
    \item \texttt{(flvector-length (make-flvector 300))} \Rightarrow 300
\end{itemize}

\begin{itemize}
    \item \texttt{(flvector-ref flvector n)} \texttt{procedure} \texttt{returns: the \( n \)th element (zero-based) of flvector}
    \item \texttt{libraries: (chezscheme)}
\end{itemize}

\( n \) must be a nonnegative fixnum strictly less than the length of \texttt{flvector}.

\begin{itemize}
    \item \texttt{(flvector-ref #vfl(-1.0 2.0 4.0 7.0) 0)} \Rightarrow -1.0
    \item \texttt{(flvector-ref #vfl(-1.0 2.0 4.0 7.0) 1)} \Rightarrow 2.0
    \item \texttt{(flvector-ref #vfl(-1.0 2.0 4.0 7.0) 3)} \Rightarrow 7.0
\end{itemize}

\begin{itemize}
    \item \texttt{(flvector-set! flvector n flonum)} \texttt{procedure} \texttt{returns: unspecified}
    \item \texttt{libraries: (chezscheme)}
\end{itemize}

\( n \) must be a nonnegative fixnum strictly less than the length of \texttt{flvector}. \texttt{flvector-set!} changes the \( n \)th element of \texttt{flvector} to \texttt{flonum}.

\begin{itemize}
    \item \texttt{(let ([v (flvector 1.0 2.0 3.0 4.0 5.0)])
               (flvector-set! v 2 (fx- (flvector-ref v 2)))
               v)} \Rightarrow \texttt{#vfl(1.0 2.0 -3.0 4.0 5.0)}
\end{itemize}
(flvector-fill! flvector flonum)

returns: unspecified
libraries: (chezscheme)

flvector-fill! replaces each element of flvector with flonum.

(let ([v (flvector 1.0 2.0 3.0)])
  (flvector-fill! v 0.0)
  v)  ⇒  #vfl(0.0 0.0 0.0)

(flvector->list flvector)

returns: a list of the elements of flvector
libraries: (chezscheme)

(flvector->list (flvector))  ⇒  ()
(flvector->list #vfl(7.0 5.0 2.0))  ⇒  (7.0 5.0 2.0)
(let ([v #vfl(1.0 2.0 3.0 4.0 5.0)])
  (apply fl* (flvector->list v)))  ⇒  120.0

(list->flvector list)

returns: an flvector of the elements of list
libraries: (chezscheme)

list must consist entirely of flonums.

(list->flvector '())  ⇒  #vfl()
(list->flvector '(3.0 5.0 7.0))  ⇒  #vfl(3.0 5.0 7.0)
(let ([v #vfl(1.0 2.0 3.0 4.0 5.0)])
  (let ([ls (flvector->list v)])
    (list->flvector (map fx* ls ls))))  ⇒  #vfl(1.0 4.0 9.0 16.0 25.0)

(flvector-copy flvector)

returns: a copy of flvector
libraries: (chezscheme)

flvector-copy creates a new flvector with the same length and contents as flvector.

(flvector-copy #vfl(3.0 4.0 5.0))  ⇒  #vfl(3.0 4.0 5.0)
(let ([v #vfl(3.0 4.0 5.0)])
  (eq? v (flvector-copy v)))  ⇒  #f
7.8. Bytevectors

As with vectors, Chez Scheme extends the syntax of bytevectors to allow the length of the vector to be specified between the # and open parenthesis, e.g., #3vu8(1 105 73). If fewer elements are supplied in the syntax than the specified length, each element after the last printed element is the same as the last printed element. This extension is disabled in an input stream after #!r6rs has been seen by the reader, unless #!chezscheme has been seen more recently.

Chez Scheme also extends the set of bytevector primitives, including primitives for loading and storing 3, 5, 6, and 7-byte quantities.

The length and indices of a bytevector in Chez Scheme are always fixnums.

All bytevectors are mutable by default, including constants. A program can create immutable bytevectors via bytevector->immutable-bytevector. Any attempt to modify an immutable bytevector causes an exception to be raised.

\[
\text{(bytevector fill ...)} \quad \text{procedure}
\]

returns: a new bytevector containing fill ...

libraries: (chezscheme)

Each fill value must be an exact integer representing a signed or unsigned 8-bit value, i.e., a value in the range -128 to 255 inclusive. A negative fill value is treated as its two’s complement equivalent.

\[
\begin{align*}
\text{(bytevector)} & \Rightarrow \ #\text{vu8}(()) \\
\text{(bytevector 1 3 5)} & \Rightarrow \ #\text{vu8}(1 3 5) \\
\text{(bytevector -1 -3 -5)} & \Rightarrow \ #\text{vu8}(255 253 251)
\end{align*}
\]

\[
\text{(bytevector->s8-list bytevector)} \quad \text{procedure}
\]

returns: a new list of the 8-bit signed elements of bytevector

libraries: (chezscheme)

The values in the returned list are exact eight-bit signed integers, i.e., values in the range -128 to 127 inclusive. bytevector->s8-list is similar to the Revised\textsuperscript{6} Report bytevector->u8-list except the values in the returned list are signed rather than unsigned.

\[
\begin{align*}
\text{(bytevector->s8-list (make-bytevector 0))} & \Rightarrow () \\
\text{(bytevector->s8-list #\text{vu8}(1 127 128 255))} & \Rightarrow (1 127 -128 -1)
\end{align*}
\]

\[
\begin{align*}
\text{(let ([v #\text{vu8}(1 2 3 255)])} \\
\text{ (apply * (bytevector->s8-list v)))} & \Rightarrow -6
\end{align*}
\]
7. Operations on Objects

(s8-list->bytevector list)  
returns: a new bytevector of the elements of list  
libraries: (chezscheme)

list must consist entirely of exact eight-bit signed integers, i.e., values in the range -128 to 127 inclusive. s8-list->bytevector is similar to the Revised6 Report procedure u8-list->bytevector, except the elements of the input list are signed rather than unsigned.

(s8-list->bytevector '()) ⇒ #vu8()  
(s8-list->bytevector '(1 127 -128 -1)) ⇒ #vu8(1 127 128 255)

(bytevector-truncate! bytevector n)  
returns: bytevector or the empty bytevector  
libraries: (chezscheme)

bytevector must be mutable. n must be an exact nonnegative fixnum not greater than the length of bytevector. If n is zero, bytevector-truncate! returns the empty bytevector. Otherwise, bytevector-truncate! destructively truncates bytevector to its first n bytes and returns bytevector.

(define bv (make-bytevector 7 19))  
(bytevector-truncate! bv 0) ⇒ #vu8()  
bv ⇒ #vu8(19 19 19 19 19 19 19)  
(bytevector-truncate! bv 3) ⇒ #vu8(19 19 19)  
bv ⇒ #vu8(19 19 19)
7.8. Bytevectors

 BYTEVECTORS

(Bytevector-u24-ref bytevector n eness) procedure
returns: the 24-bit unsigned integer at index n (zero-based) of bytevector

(Bytevector-s24-ref bytevector n eness) procedure
returns: the 24-bit signed integer at index n (zero-based) of bytevector

(Bytevector-u40-ref bytevector n eness) procedure
returns: the 40-bit unsigned integer at index n (zero-based) of bytevector

(Bytevector-s40-ref bytevector n eness) procedure
returns: the 40-bit signed integer at index n (zero-based) of bytevector

(Bytevector-u48-ref bytevector n eness) procedure
returns: the 48-bit unsigned integer at index n (zero-based) of bytevector

(Bytevector-s48-ref bytevector n eness) procedure
returns: the 48-bit signed integer at index n (zero-based) of bytevector

(Bytevector-u56-ref bytevector n eness) procedure
returns: the 56-bit unsigned integer at index n (zero-based) of bytevector

(Bytevector-s56-ref bytevector n eness) procedure
returns: the 56-bit signed integer at index n (zero-based) of bytevector

libraries: (chezscheme)

n must be an exact nonnegative integer and indexes the starting byte of the value. The sum of n and the number of bytes occupied by the value (3 for 24-bit values, 5 for 40-bit values, 6 for 48-bit values, and 7 for 56-bit values) must not exceed the length of bytevector. eness must be a valid endianness symbol naming the endianness.

The return value is an exact integer in the appropriate range for the number of bytes occupied by the value. Signed values are the equivalent of the stored value treated as a two’s complement value.

(Bytevector-u24-set! bytevector n u24 eness) procedure
(Bytevector-s24-set! bytevector n s24 eness) procedure
(Bytevector-u40-set! bytevector n u40 eness) procedure
(Bytevector-s40-set! bytevector n s40 eness) procedure
(Bytevector-u48-set! bytevector n u48 eness) procedure
(Bytevector-s48-set! bytevector n s48 eness) procedure
(Bytevector-u56-set! bytevector n u56 eness) procedure
(Bytevector-s56-set! bytevector n s56 eness) procedure

returns: unspecified
libraries: (chezscheme)

bytevector must be mutable. n must be an exact nonnegative integer and indexes the starting byte of the value. The sum of n and the number of bytes occupied by the value must not exceed the length of bytevector. u24 must be a 24-bit unsigned value, i.e., a value in the range 0 to $2^{24} - 1$ inclusive; s24 must be a 24-bit signed value, i.e., a value in the range $-2^{23}$ to $2^{23} - 1$ inclusive; u40 must be a 40-bit unsigned value, i.e., a value in the range 0 to $2^{40} - 1$ inclusive; s40 must be a 40-bit signed value, i.e., a value in the range $-2^{39}$ to $2^{39} - 1$ inclusive; u48 must be a 48-bit unsigned value, i.e., a value in the range 0 to $2^{48} - 1$ inclusive; s48 must be a 48-bit signed value, i.e., a value in the range $-2^{47}$ to $2^{47} - 1$ inclusive; u56 must be a 56-bit unsigned value, i.e., a value in the range 0 to $2^{56} - 1$ inclusive; s56 must be a 56-bit signed value, i.e., a value in the range $-2^{55}$ to $2^{55} - 1$ inclusive.
inclusive; and $s56$ must be a 56-bit signed value, i.e., a value in the range $-2^{55}$ to $2^{55} - 1$ inclusive. $eness$ must be a valid endianness symbol naming the endianness.

These procedures store the given value in the 3, 5, 6, or 7 bytes starting at index $n$ (zero-based) of $bytevector$. Negative values are stored as their two’s complement equivalent.

*(mutable-bytevector? obj)* procedure

returns: #t if obj is a mutable bytevector, #f otherwise

*(immutable-bytevector? obj)* procedure

returns: #t if obj is an immutable bytevector, #f otherwise

libraries: (chezscheme)

(mutable-bytevector? (bytevector 1 2 3)) ⇒ #t
(mutable-bytevector? (bytevector->immutable-bytevector (bytevector 1 2 3))) ⇒ #f
(immutable-bytevector? (bytevector 1 2 3)) ⇒ #f
(immutable-bytevector? (bytevector->immutable-bytevector (bytevector 1 2 3))) ⇒ #t
(immutable-bytevector? (cons 3 4)) ⇒ #f

*(bytevector->immutable-bytevector bytevector)* procedure

returns: an immutable bytevector equal to bytevector

libraries: (chezscheme)

The result is bytevector itself if bytevector is immutable; otherwise, the result is an immutable bytevector with the same content as bytevector.

(define bv (bytevector->immutable-bytevector (bytevector 1 2 3)))
(bytevector-u8-set! bv 0 0) ⇒ exception: not mutable

*(bytevector-compress bytevector)* procedure

returns: a new bytevector containing compressed content of bytevector

libraries: (chezscheme)

The result is the raw compressed data with a minimal header to record the uncompressed size and the compression mode. The result does not include the header that is written by port-based compression using the compressed option. The compression format is determined by the compress-format parameter, and the compression level is determined by the compress-level parameter.

*(bytevector-uncompress bytevector)* procedure

returns: a bytevector containing uncompressed content of bytevector

libraries: (chezscheme)

Uncompresses a bytevector produced by bytevector-compress to a new bytevector with the same content as the original given to bytevector-compress.
7.9. Stencil Vectors

Stencil vectors are like vectors, but also have a *mask*, accessible via `stencil-vector-mask`, which is a fixnum of no more than `(stencil-vector-mask-width)` bits. The length of a stencil vector is exactly the same as the number of bits set in its mask. In other words, the following expression is true for any stencil vector `sv`:

```scheme
(fx= (stencil-vector-length sv) (fxpopcount (stencil-vector-mask sv)))
```

Since `(stencil-vector-mask-width)` can be no more than the number of bits in a fixnum, the maximum size of a stencil vector is limited.

Other than the `stencil-vector` constructor, the mask is only relevant to the `stencil-vector-update` and `stencil-vector-truncate!` procedures.

A stencil vector provides a more compact representation than a vector with one element dedicated to the mask. It also provides more efficient functional update through the `stencil-vector-update` procedure. A stencil vector is useful, for example, to implement sparse nodes in a trie.

Stencil vectors are written with the prefix `#`, then a mask integer, then `vs`, and followed by a parenthesized sequence of elements. Note that the mask integer determines the length of the stencil vector, and it uses the same position as the length of a vector, but the mask is not optional. Also, the number of elements in the parenthesized sequence must match exactly the number of bits set in the mask. The stencil vector syntax is disabled in an input stream after `#!r6rs` has been seen by the reader, unless `#!chezscheme` has been seen more recently.

```scheme
(stencil-vector-mask-width) procedure
returns: a fixnum: the number of bits in a stencil vector mask
libraries: (chezscheme)
```

The result is always less than `(fixnum-width)`.

```scheme
(stencil-vector? obj) procedure
returns: #t if obj is a stencil vector, #f otherwise
libraries: (chezscheme)
```

```scheme
(stencil-vector? (stencil-vector #b11 'x 'y)) ⇒ #t
(stencil-vector? '#3vs(x y)) ⇒ #t
(stencil-vector? '#2(x y)) ⇒ #f
```

```scheme
(stencil-vector mask obj ...) procedure
returns: a stencil vector with the given mask and content
libraries: (chezscheme)
```

`mask` must be a nonnegative fixnum less than `(fxsll 1 (stencil-vector-mask-width))`, and the number of supplied `objs` must be the same as `(fxpopcount mask)`. 
(stencil-vector #b11 'x 'y) ⇒ #3vs(x y)
(stencil-vector #b10101 'x 'y 'z) ⇒ #21vs(x y z)

(stencil-vector-mask stencil-vector) procedure
returns: the mask of stencil-vector
libraries: (chezscheme)

(stencil-vector-length stencil-vector) procedure
returns: the length of stencil-vector
libraries: (chezscheme)

A stencil vector’s length is determined by its mask. (I.e., this is equivalent to
(fxpopcount (stencil-vector-mask stencil-vector)).)

(stencil-vector-mask '#0vs()) ;= 0
(stencil-vector-length '#0vs()) ;= 0
(stencil-vector-mask '#21vs(x y z)) ;= 21
(stencil-vector-length '#21vs(x y z)) ;= 3

(stencil-vector-ref stencil-vector n) procedure
returns: the object at position n in stencil-vector
libraries: (chezscheme)
n must be a nonnegative fixnum that is less than the length of stencil-vector.
Stencil vector elements are accessed by position, unrelated to the stencil vector’s mask
(except insofar as the number of valid positions is determined by the mask).
Conceptually, each stencil vector element corresponds to a bit in the stencil vector’s mask
(and vice-versa). To convert a (0-based) bit position bit to an index, where the lowest set
bit corresponds to the first element of the stencil vector, use the following calculation:
(fxpopcount (fxand (stencil-vector-mask stencil-vector) (fx- (fxsll 1 bit) 1)))

(stencil-vector-ref '#21vs(x y z) 0) ;= x
(stencil-vector-ref '#21vs(x y z) 2) ;= z

(stencil-vector-set! stencil-vector n obj) procedure
returns: unspecified
libraries: (chezscheme)
n must be a nonnegative fixnum that is less than the length of stencil-vector.
Installs obj at position n within stencil-vector. See stencil-vector-ref for more informa-
tion about positions in stencil vectors.
(define sv (stencil-vector #b10101 'x 'y 'z))
(stencil-vector-set! sv 1 'why)
sv ⇒ #21vs(x why z)

(stencil-vector-update stencil-vector remove-bits add-bits obj ...) procedure
returns: a new stencil vector adapted from stencil-vector
libraries: (chezscheme)

remove-bits and add-bits must be nonnegative fixnums less than
(fxsl1 1 (stencil-vector-mask-width)). Furthermore, all of the following must be true:

- remove-bits must be a subset of the bits in the mask of stencil-vector. In other
  words, (logand (stencil-vector-mask stencil-vector) remove-bits) must be equal
to remove-bits.
- add-bits must have a set of bits that do not overlap the subtraction of remove-bits
  from the mask of stencil-vector. In other words

  \[(\logand \left(\logand \text{stencil-vector-mask stencil-vector} \& \text{lognot remove-bits}\right) \text{add-bits})\]

  must be 0.
- The number of supplied objs must match (fxpopcount add-bits).

Returns a new stencil vector that has all of the elements of stencil-vector, except the ones
identified by the bits in remove-bits. The new stencil vector also has the given objs at posi-
tions determined by add-bits. Elements copied from stencil-vector to the new vector retain
their relative positions corresponding to their bits in the stencil-vector mask. Individual
bits in the mask, remove-bits, and add-bits are mapped to element positions as described
in the documentation of stencil-vector-ref. The mask of the new stencil vector is the
mask of stencil-vector minus remove-bits plus add-bits.

(define st-vec (stencil-vector #b101 'a 'b))
(stencil-vector-update st-vec #b0 #b10 'c) ⇒ #7vs(a c b)
(stencil-vector-update st-vec #b0 #b1000 'c) ⇒ #13vs(a b c)
st-vec ⇒ #5vs(a b)
(stencil-vector-update st-vec #b1 #b1 'c) ⇒ #5vs(c b)
(stencil-vector-update st-vec #b100 #b100 'c) ⇒ #5vs(a c)
(stencil-vector-update st-vec #b100 #b0) ⇒ #1vs(a)

(stencil-vector-truncate! stencil-vector mask) procedure
returns: unspecified
libraries: (chezscheme)

mask must be a nonnegative fixnum that does not have more bits set than bits set in the
current mask of stencil-vector.
Changes the mask of *stencil-vector* to *mask*, discarding any elements of the vector beyond the first \((\text{fxpopcount } mask)\) elements. There is no requirement that *mask* has any bits in common with the current mask of *stencil-vector*.

### 7.10. Boxes

Boxes are single-cell objects that are primarily useful for providing an “extra level of indirection.” This extra level of indirection is typically used to allow more than one body of code or data structure to share a reference, or pointer, to an object. For example, boxes may be used to implement *call-by-reference* semantics in an interpreter for a language employing this parameter passing discipline.

Boxes are written with the prefix \(#&\) (pronounced “hash-ampersand”). For example, \(#&(a b c)\) is a box holding the list \((a b c)\). The box syntax is disabled in an input stream after \(#!r6rs\) has been seen by the reader, unless \(#!chezscheme\) has been seen more recently.

All boxes are mutable by default, including constants. A program can create immutable boxes via `box-immutable`. Any attempt to modify an immutable box causes an exception to be raised.

```
(box? obj)  procedure
returns: #t if obj is a box, #f otherwise
libraries: (chezscheme)

(box? '#&a) ⇒ #t
(box? 'a) ⇒ #f
(box? (box 3)) ⇒ #t
```

```
(box obj)  procedure
returns: a new box containing obj
libraries: (chezscheme)

(box 'a) ⇒ #&a
(box (box '(a b c))) ⇒ #&#&(a b c)
```

```
(unbox box)  procedure
returns: contents of box
libraries: (chezscheme)

(unbox #&a) ⇒ a
(unbox #&#&(a b c)) ⇒ #&(a b c)

(let ([b (box "hi")])
  (unbox b)) ⇒ "hi"
```
(set-box! box obj)

returns: unspecified

libraries: (chezscheme)

box must be mutable. set-box! sets the contents of box to obj.

(let ([b (box 'x)])
  (set-box! b 'y)
  b) ⇒ #\&y

(let ([incr!
       (lambda (x)
           (set-box! x (+ (unbox x) 1)))]
     (let ([b (box 3)])
       (incr! b)
       (unbox b))) ⇒ 4

(box-cas! box old-obj new-obj)

returns: #t if box is changed, #f otherwise

libraries: (chezscheme)

box must be mutable. box-cas! atomically changes the content of box to new-obj if the replaced content is eq? to old-obj. If the content of box that would be replaced is not eq? to old-obj, then box is unchanged.

On an architecture with a weak memory model, box-cas! can spuriously fail, leaving box unchanged and returning #f even if the current value in box is old-obj. On success, no memory ordering is implied, which means that memory-order-acquire and/or memory-order-release may be needed to complete an intended synchronization.

(define b (box 'old))
(box-cas! b 'old 'new) ⇒ #t, assuming no spurious failure
(unbox b) ⇒ 'new
(box-cas! b 'other 'wrong) ⇒ #f
(unbox b) ⇒ 'new

(mutable-box? obj)

returns: #t if obj is a mutable box, #f otherwise

(immutable-box? obj)

returns: #t if obj is an immutable box, #f otherwise

libraries: (chezscheme)

(mutable-box? (box 1)) ⇒ #t
(mutable-box? (box-immutable 1)) ⇒ #f
(immutable-box? (box 1)) ⇒ #f
(immutable-box? (box-immutable 1)) ⇒ #t
(mutable-box? (cons 3 4)) ⇒ #f
7. Operations on Objects

(box-immutable obj) procedure
returns: a new immutable box containing obj
libraries: (chezscheme)

Boxes are typically intended to support shared, mutable structure, so immutable boxes are not often useful.

(define b (box-immutable 1))
(set-box! b 0) ⇒ exception: not mutable

7.11. Symbols

Chez Scheme extends the standard symbol syntax in several ways:

- Symbol names may begin with @, but ,@abc is parsed as (unquote-splicing abc); to produce (unquote @abc) one can type , @abc, \x40;abc, or ,|@abc|.
- The single-character sequences { and } are read as symbols.
- A symbol’s name may begin with any character that might normally start a number, including a digit, ., +, -, as long as the delimited sequence of characters starting with that character cannot be parsed as a number.
- A symbol whose name contains arbitrary characters may be written by escaping them with \ or with |. \ is used to escape a single character (except ‘x’, since \x marks the start of a hex scalar value), whereas | is used to escape the group of characters that follow it up through the matching |.

The printer always prints symbols using the standard R6RS syntax, so that, e.g., @abc prints as \x40;abc and 1- prints as \x31;-.

Gensyms are printed #{ and } brackets that enclose both the “pretty” and “unique” names, e.g., #{g1426 e5g1c94g642dssw-a}. They may also be printed using the pretty name only with the prefix #:, e.g., #:g1426.

These extensions are disabled in an input stream after #!r6rs has been seen by the reader, unless #!chezscheme has been seen more recently.

(gensym) procedure
(gensym pretty-name) procedure
(gensym pretty-name unique-name) procedure
returns: a unique generated symbol
libraries: (chezscheme)

Each call to gensym returns a unique generated symbol, or gensym. Each generated symbol has two names: a “pretty” name and a “unique” name.

In the first form above, the pretty name is formed (lazily—see below) by combining an internal prefix with the value of an internal counter. After each name is formed, the internal counter is incremented. The parameters gensym-prefix and gensym-count, described
below, may be used to access and set the internal prefix and counter. By default, the
prefix is the single-character string "g". In the second and third forms, the pretty name of
the new gensym is \textit{pretty-name}, which must be a string. The pretty name of a gensym is
returned by the procedure \texttt{symbol->string}.

In both the first and second forms, the unique name is an automatically generated globally
unique name. Globally unique names are constructed (lazily—see below) from the com-
bination of a universally unique identifier and an internal counter. In the third form of
gensym, the unique name of the new gensym is \textit{unique-name}, which must be a string. The
unique name of a gensym may be obtained via the procedure \texttt{gensym->unique-string}.

The unique name allows gensyms to be written in such a way that they can be read back
and reliably commonized on input. The syntax for gensyms includes both the pretty name
and the unique name, as shown in the example below:

\begin{verbatim}
(gensym) ⇒ #{g0 bcsfg5eq4e9b3h9o-a}
\end{verbatim}

When the parameter \texttt{print-gensym} is set to \texttt{pretty}, the printer prints the pretty name
only, with a #: syntax, so

\begin{verbatim}
(parameterize ([print-gensym 'pretty])
  (write (gensym)))
\end{verbatim}

prints #:g0.

When the reader sees the #: syntax, it produces a gensym with the given pretty name, but
the original unique name is lost.

When the parameter is set to #f, the printer prints just the pretty name, so

\begin{verbatim}
(parameterize ([print-gensym #f])
  (write (gensym)))
\end{verbatim}

prints g0. This is useful only when gensyms do not need to be read back in as gensyms.

In order to reduce construction and (when threaded) synchronization overhead when gen-
syms are frequently created but rarely printed or stored in an object file, generated pretty
and unique names are created lazily, i.e., not until first requested, either by the printer, fast
writer, or explicitly by one of the procedures \texttt{symbol->string} or \texttt{gensym->unique-string}.

In addition, a gensym is not placed into the system's internal symbol table (the oblist; see
page 174) until the unique name is requested. This allows a gensym to be reclaimed by the
storage manager if no references to the gensym exist and no unique name exists by which
to access it, even if it has a top-level binding or a nonempty property list.

\begin{verbatim}
(define x (gensym))
x ⇒ #{g2 bcsfg5eq4e9b3h9o-c}
(symbol->string x) ⇒ "g2"
(gensym->unique-string x) ⇒ "bcsfg5eq4e9b3h9o-c"
\end{verbatim}

Gensyms subsume the notion of \textit{uninterned symbols} supported by earlier versions of
\textit{Chez Scheme}. For most purposes, the predicate \texttt{uninterned-symbol?} has been replaced by
\texttt{gensym?}.
The parameters `gensym-prefix` and `gensym-count` are used to access and set the internal prefix and counter from which the pretty name of a gensym is generated when `gensym` is not given an explicit string argument. `gensym-prefix` defaults to the string "g" and may be set to any object. `gensym-count` starts at 0 and may be set to any nonnegative integer.

As described above, Chez Scheme delays the creation of the pretty name until the name is first requested by the printer or by an explicit call to `symbol->string`. These parameters are not consulted until that time; setting them when `gensym` is called thus has no effect on the generated name.

```
(let ([x (parameterize ([gensym-prefix "genny"]
                         [gensym-count 17]
                         [print-gensym 'pretty])
               (gensym))])
  (format "-s" x)) ⇒ "#{g4 bcsfg5eq4e9b3h9o-e}"
(let ([x (gensym)])
  (parameterize ([gensym-prefix "genny"]
                 [gensym-count 17]
                 [print-gensym #f])
    (format "-s" (gensym)))) ⇒ "genny17"
```

### (gensym->unique-string gensym)

**procedure**

returns: the unique name of `gensym`

libraries: (chezscheme)

```
(gensym->unique-string (gensym)) ⇒ "bd3kufa7ypjcvut-g"
```

### (gensym? obj)

**procedure**

returns: #t if `obj` is a gensym, #f otherwise

libraries: (chezscheme)

```
(gensym? (string->symbol "z")) ⇒ #f
(gensym? (gensym "z")) ⇒ #t
(gensym? 'a) ⇒ #f
(gensym? 3) ⇒ #f
(gensym? (gensym)) ⇒ #t
(gensym? '#{g2 bcsfg5eq4e9b3h9o-c}) ⇒ #t
```

### (string->uninterned-symbol str)

**procedure**

returns: a fresh uninterned symbol

libraries: (chezscheme)

`str` must be a string.
Returns an uninterned symbol that prints the same as a symbol constructed from \texttt{str}, but which is not \texttt{eq?} to any other symbol.

When an uninterned symbol is converted by the fasl writer, the fasl reader will allocate a fresh uninterned symbol each time the fasl stream is read. Multiple occurrences of the same uninterned symbol in the fasl writer's argument will become multiple occurrences of the same new uninterned symbol in the fasl reader's result for the stream.

\begin{verbatim}
(string->uninterned-symbol "z") \Rightarrow z
(uninterned-symbol? (string->uninterned-symbol "z")) \Rightarrow #t
(symbol? (string->uninterned-symbol "z")) \Rightarrow #t
(gensym? (string->uninterned-symbol "z")) \Rightarrow #f
\end{verbatim}

\begin{verbatim}
(uninterned-symbol? obj) \hspace{1cm} \textbf{procedure}
returns: \#t if \textit{obj} is an uninterned symbol, \#f otherwise
libraries: (chezscheme)
\end{verbatim}

\begin{verbatim}
(uninterned-symbol? (string->symbol "z")) \Rightarrow #f
(uninterned-symbol? (gensym "z")) \Rightarrow #f
(uninterned-symbol? (string->uninterned-symbol "z")) \Rightarrow #t
\end{verbatim}

\begin{verbatim}
(putprop symbol key value) \hspace{1cm} \textbf{procedure}
returns: unspecified
libraries: (chezscheme)
\end{verbatim}

\textit{Chez Scheme} associates a property list with each symbol, allowing multiple key-value pairs to be stored directly with the symbol. New key-value pairs may be placed in the property list or retrieved in a manner analogous to the use of association lists, using the procedures \texttt{putprop} and \texttt{getprop}. Property lists are often used to store information related to the symbol itself. For example, a natural language program might use symbols to represent words, using their property lists to store information about use and meaning.

\texttt{putprop} associates \texttt{value} with \texttt{key} on the property list of \texttt{symbol}. \texttt{key} and \texttt{value} may be any types of object, although \texttt{key} is typically a symbol.

\texttt{putprop} may be used to establish a new property or to change an existing property.

See the examples under \texttt{getprop} below.

\begin{verbatim}
(getprop symbol key) \hspace{1cm} \textbf{procedure}
(getprop symbol key default) \hspace{1cm} \textbf{procedure}
returns: the value associated with \texttt{key} on the property list of \texttt{symbol}
libraries: (chezscheme)
\end{verbatim}

\texttt{getprop} searches the property list of \texttt{symbol} for a key identical to \texttt{key} (in the sense of \texttt{eq?}), and returns the value associated with this key, if any. If no value is associated with \texttt{key} on the property list of \texttt{symbol}, \texttt{getprop} returns \texttt{default}, or \#f if the \texttt{default} argument is not supplied.
7. Operations on Objects

(putprop 'fred 'species 'snurd)
(putprop 'fred 'age 4)
(putprop 'fred 'colors '(black white))

(getprop 'fred 'species) ⇒ snurd
(getprop 'fred 'colors) ⇒ (black white)
(getprop 'fred 'nonkey) ⇒ #f
(getprop 'fred 'nonkey 'unknown) ⇒ unknown

(putprop 'fred 'species #f)
(getprop 'fred 'species 'unknown) ⇒ #f

(remprop symbol key) procedure
returns: unspecified
libraries: (chezscheme)

remprop removes the property with key key from the property list of symbol, if such a property exists.

(putprop 'fred 'species 'snurd)
(getprop 'fred 'species) ⇒ snurd

(remprop 'fred 'species)
(getprop 'fred 'species 'unknown) ⇒ unknown

(property-list symbol) procedure
returns: a copy of the internal property list for symbol
libraries: (chezscheme)

A property list is a list of alternating keys and values, i.e., (key value ...).

(putprop 'fred 'species 'snurd)
(putprop 'fred 'colors '(black white))
(property-list 'fred) ⇒ (colors (black white) species snurd)

(oblist) procedure
returns: a list of interned symbols
libraries: (chezscheme)

The system maintains an internal symbol table used to insure that any two occurrences of the same symbol name resolve to the same symbol object. The oblist procedure returns a list of the symbols currently in this symbol table.

The list of interned symbols grows when a new symbol is introduced into the system or when the unique name of a gensym (see page 170) is requested. It shrinks when the garbage collector determines that it is safe to discard a symbol. It is safe to discard a symbol only if the symbol is not accessible except through the oblist, has no top-level binding, and has no properties on its property list.
The first example above follows from the property that all interned symbols are in the oblist from the time they are read, which happens prior to evaluation. The second example follows from the fact that no symbols can be removed from the oblist while references to those symbols exist, in this case, within the list returned by the first call to `oblist` (whichever call is performed first). The expression in the third example can return `#f` only if a garbage collection occurs sometime between the two calls to `oblist`, and only if one or more symbols are removed from the oblist by that collection.

7.12. Void

Many Scheme operations return an unspecified result. Chez Scheme typically returns a special `void` object when the value returned by an operation is unspecified. The Chez Scheme void object is not meant to be used as a datum, and consequently does not have a reader syntax. As for other objects without a reader syntax, such as procedures and ports, Chez Scheme output procedures print the void object using a nonreadable representation, i.e., `<void>`. Since the void object should be returned only by operations that do not have “interesting” values, the default waiter printer (see `waiter-write`) suppresses the printing of the void object. `set!`, `set-car!`, `load`, and `write` are examples of Chez Scheme operations that return the void object.

<table>
<thead>
<tr>
<th>(void)</th>
<th>procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>returns: the void object</td>
<td></td>
</tr>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

`void` is a procedure of no arguments that returns the void object. It can be used to force expressions that are used for effect or whose values are otherwise unspecified to evaluate to a consistent, trivial value. Since most Chez Scheme operations that are used for effect return the void object, however, it is rarely necessary to explicitly invoke the `void` procedure.

Since the void object is used explicitly as an “unspecified” value, it is a bad idea to use it for any other purpose or to count on any given expression evaluating to the void object.

The default waiter printer suppresses the void object; that is, nothing is printed for expressions that evaluate to the void object.

```
(eq? (void) #f)  ⇒  #f
(eq? (void) #t)  ⇒  #f
(eq? (void) '()) ⇒  #f
```
7.13. Sorting

\[
\begin{align*}
\text{sort} & \quad \text{procedure} \\
\text{sort!} & \quad \text{procedure}
\end{align*}
\]
returns: a list containing the elements of \texttt{list} sorted according to \texttt{predicate}

\[\text{libraries: (chezscheme)}\]

\texttt{sort} is identical to the Revised\textsuperscript{6} Report \texttt{list-sort}, and \texttt{sort!} is a destructive version of \texttt{sort}, i.e., it reuses pairs from the input list to form the output list.

\[
\begin{align*}
\text{(sort < '(3 4 2 1 2 5))} & \Rightarrow (1 \ 2 \ 2 \ 3 \ 4 \ 5) \\
\text{(sort! < '(3 4 2 1 2 5))} & \Rightarrow (1 \ 2 \ 2 \ 3 \ 4 \ 5)
\end{align*}
\]

\[
\begin{align*}
\text{(merge predicate list\textsubscript{1} list\textsubscript{2})} & \quad \text{procedure} \\
\text{merge!} & \quad \text{procedure}
\end{align*}
\]
returns: \texttt{list\textsubscript{1}} merged with \texttt{list\textsubscript{2}} in the order specified by \texttt{predicate}

\[\text{libraries: (chezscheme)}\]

\texttt{predicate} should be a procedure that expects two arguments and returns \#t if its first argument must precede its second in the merged list. It should not have any side effects. That is, if \texttt{predicate} is applied to two objects \(x\) and \(y\), where \(x\) is taken from the second list and \(y\) is taken from the first list, it should return true only if \(x\) should appear before \(y\) in the output list. If this constraint is met, \texttt{merge} and \texttt{merge!} are stable, in that items from \texttt{list\textsubscript{1}} are placed in front of equivalent items from \texttt{list\textsubscript{2}} in the output list. Duplicate elements are included in the merged list.

\texttt{merge!} combines the lists destructively, using pairs from the input lists to form the output list.

\[
\begin{align*}
\text{(merge char<? '('#\a #\c) '('#\b #\c #\d))} & \Rightarrow ('#\a ' #\b ' #\c ' #\c ' #\d) \\
\text{(merge < ' (1/2 2/3 3/4) ' (0.5 0.6 0.7))} & \Rightarrow (1/2 0.5 0.6 2/3 0.7 3/4)
\end{align*}
\]

7.14. Hashtables

\textit{Chez Scheme} provides several extensions to the hashtable mechanism, including a mechanism for directly accessing a key, value pair in a hashtable, support for weak eq and eqv hashtables, and a set of procedures specialized to eq and symbol hashtables.

\[
\begin{align*}
\text{(hashtable-cell hashtable key default)} & \quad \text{procedure} \\
\text{returns: a pair (see below)} \\
\text{libraries: (chezscheme)}
\end{align*}
\]

\texttt{hashtable} must be a mutable hashtable. \texttt{key} and \texttt{default} may be any Scheme values.
If no value is associated with key in hashtable, hashtable-cell modifies hashtable to associate key with default. It returns a pair whose car is key and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate key with a new value. The key in the car field should not be changed. The advantage of this procedure over the Revised⁶ Report procedures for manipulating hashtable entries is that the value associated with a key may be read or written many times with only a single hashtable lookup.

```
(define ht (make-eq-hashtable))
(define v (vector 'a 'b 'c))
(define cell (hashtable-cell ht v 3))
cell ⇒ (#(a b c) . 3)
(hashtable-ref ht v 0) ⇒ 3
(set-cdr! cell 4)
(hashtable-ref ht v 0) ⇒ 4
```

(hashtable-ref-cell hashtable key)
procedure
returns: a pair if key is in hashtable, #f otherwise
libraries: (chezscheme)

hashtable must be a mutable hashtable. key may be any Scheme value.

If key is associated with a value in hashtable, then hashtable-ref-cell returns a pair whose car is key and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate key with a new value. The key in the car field should not be changed.

If key is not in hashtable, then #f is returned.

```
(define ht (make-eq-hashtable))
(define v (vector 'a 'b 'c))
(hashtable-ref-cell ht v) ⇒ #f
(hashtable-set! ht v 3)
(define cell (hashtable-ref-cell ht v))
cell ⇒ ((#a b c) . 3)
(hashtable-ref ht v 0) ⇒ 3
(set-cdr! cell 4)
(hashtable-ref ht v 0) ⇒ 4
```

(hashtable-keys hashtable)
procedure
(hashtable-keys hashtable size)
procedure
returns: a vector containing the keys in hashtable
libraries: (chezscheme)

Identical to the Revised⁶ Report counterpart, but allowing an optional size argument. If size is specified, then it must be an exact, nonnegative integer; the result vector will contain (min size (hashtable-size hashtable)) elements. Different calls to hashtable-keys with
a size less than \( \text{hashtable-size } \text{hashtable} \) may return different subsets of \text{hashtable}'s keys.

\[
\text{(define ht (make-eq-hashtable))}
\]
\[
\text{(hashtable-set! ht 'a "one")}
\]
\[
\text{(hashtable-set! ht 'b "two")}
\]
\[
\text{(hashtable-set! ht 'c "three")}
\]
\[
\text{(hashtable-keys ht)} \Rightarrow \text{#(a b c) or any permutation}
\]
\[
\text{(hashtable-keys ht 1)} \Rightarrow \text{#(a) or #(b) or #(c)}
\]

\[
\text{(hashtable-values \text{hashtable})}
\]
\[
\text{(hashtable-values \text{hashtable size})}
\]

returns: a vector containing the values in \text{hashtable}

libraries: (chezscheme)

Each value is the value of one of the keys in \text{hashtable}. Duplicate values are not removed. The values may appear in any order in the returned vector. If size is specified, then it must be an exact, nonnegative integer; the result vector will contain \( \text{(min size (hashtable-size \text{hashtable}) \text{hashtable})} \) elements. Different calls to \text{hashtable-values} with a size less than \( \text{(hashtable-size \text{hashtable})} \) may return different subsets of \text{hashtable}'s values.

\[
\text{(define ht (make-eq-hashtable))}
\]
\[
\text{(define p1 (cons 'a 'b))}
\]
\[
\text{(define p2 (cons 'a 'b))}
\]
\[
\text{(hashtable-set! ht p1 "one")}
\]
\[
\text{(hashtable-set! ht p2 "two")}
\]
\[
\text{(hashtable-set! ht 'q "two")}
\]
\[
\text{(hashtable-values ht)} \Rightarrow \text{#("one" "two" "two") or any permutation}
\]
\[
\text{(hashtable-values ht 1)} \Rightarrow \text{#("one") or #("two")}
\]

This procedure is equivalent to calling \text{hashtable-entries} and returning only the second result, but it is more efficient since the separate vector of keys need not be created.

\[
\text{(hashtable-entries \text{hashtable})}
\]
\[
\text{(hashtable-entries \text{hashtable size})}
\]

returns: two vectors containing the keys and values in \text{hashtable}

libraries: (chezscheme)

Identical to the Revised\(^6\) Report counterpart, but allowing an optional size argument. If size is specified, then it must be an exact, nonnegative integer; the result vectors will each contain \( \text{(min size (hashtable-size \text{hashtable}) \text{hashtable})} \) elements. Different calls to \text{hashtable-entries} with a size less than \( \text{(hashtable-size \text{hashtable})} \) may return different subsets of \text{hashtable}'s entries.
(define ht (make-eq-hashtable))
(hashtable-set! ht 'a "one")
(hashtable-set! ht 'b "two")
(hashtable-entries ht) ⇒ #(a b) #("one" "two") or the other permutation
(hashtable-entries ht 1) ⇒ #(a) #("one") or #(b) #("two")

(hashtable-cells hashtable) procedure
(hashtable-cells hashtable size) procedure
returns: a vector of up to size elements containing the cells of hashtable
libraries: (chezscheme)

hashtable must be a mutable hashtable.

Each element of the result vector is the value of one of the cells in hashtable. The cells may appear in any order in the returned vector. If size is specified, then it must be an exact, nonnegative integer; the result vector will contain \((\text{min} \ size \ \text{(hashtable-size hashtable)})\) elements. If size is not specified, then the result vector has \((\text{hashtable-size hashtable})\) elements. Different calls to hashtable-cells with a size less than \((\text{hashtable-size hashtable})\) may return different subsets of hashtable’s cells.

Changing the cdr of a pair in the result vector effectively updates the table to associate car of the pair with a new value. The car of a pair in the result vector should not be changed.

(define ht (make-eqv-hashtable))
(hashtable-set! ht 1 'one)
(hashtable-set! ht 2 'two)
(hashtable-cells ht) ⇒ #((1 . one) (2 . two)) or #((2 . two) (1 . one))
(hashtable-cells ht 1) ⇒ #((1 . one)) or #((2 . two))
(hashtable-cells ht 0) ⇒ #()

(make-weak-eq-hashtable) procedure
(make-weak-eq-hashtable size) procedure
(make-weak-eqv-hashtable) procedure
(make-weak-eqv-hashtable size) procedure
(make-weak-hashtable hash equiv?) procedure
(make-weak-hashtable hash equiv? size) procedure
returns: a new weak hashtable
libraries: (chezscheme)

Like the Revised\(^6\) Report procedures make-eq-hashtable, make-eqv-hashtable, and make-hashtable, except the keys of the hashtable are held weakly, i.e., they are not protected from the garbage collector. Keys reclaimed by the garbage collector are removed from the table, and their associated values are dropped the next time the table is modified, if not sooner.

Values in the hashtable are referenced normally as long as the key is not reclaimed, since keys are paired values using weak pairs. Consequently, if a value in the hashtable
7. Operations on Objects

refers to its own key, then garbage collection is prevented from reclaiming the key. See make-ephemeron-hashtable and related functions.

A copy of a weak hashtable created by hashtable-copy is also weak. If the copy is immutable, inaccessible keys may still be dropped from the hashtable, even though the contents of the table is otherwise unchanging. The effect of this can be observed via hashtable-keys and hashtable-entries.

(define ht1 (make-weak-eq-hashtable))
(define ht2 (make-weak-eq-hashtable 32))

(define ht1 (make-ephemeron-eq-hashtable))
(define ht2 (make-ephemeron-eq-hashtable 32))

(define ht1 (make-weak-eq-hashtable))
(define ht2 (hashtable-copy ht1))
(hashtable-weak? ht2) ⇒ #t

(define ht1 (make-ephemeron-eq-hashtable))
(define ht2 (hashtable-copy ht1))
(hashtable-ephemeron? ht2) ⇒ #t
(eq-hashtable? obj)  
procedure
returns: #t if obj is an eq hashtable, #f otherwise
libraries: (chezscheme)

(eq-hashtable? (make-eq-hashtable))  ⇒  #t
(eq-hashtable? '(not a hash table))  ⇒  #f

(eq-hashtable-weak? hashtable)  
procedure
returns: #t if hashtable is weak, #f otherwise
libraries: (chezscheme)

hashtable must be an eq hashtable.

(eq-hashtable-weak? (make-eq-hashtable))  ⇒  #f
(eq-hashtable-weak? (make-weak-eq-hashtable))  ⇒  #t

(eq-hashtable-ephemeron? hashtable)  
procedure
returns: #t if hashtable uses ephemeron pairs, #f otherwise
libraries: (chezscheme)

hashtable must be an eq hashtable.

(eq-hashtable-ephemeron? (make-eq-hashtable))  ⇒  #f
(eq-hashtable-ephemeron? (make-ephemeron-eq-hashtable))  ⇒  #t

(eq-hashtable-set! hashtable key value)  
procedure
returns: unspecified
libraries: (chezscheme)

hashtable must be a mutable eq hashtable. key and value may be any Scheme values.
eq-hashtable-set! associates the value value with the key key in hashtable.

(define ht (make-eq-hashtable))
(eq-hashtable-set! ht 'a 73)

(eq-hashtable-ref hashtable key default)  
procedure
returns: see below
libraries: (chezscheme)

hashtable must be an eq hashtable. key and default may be any Scheme values.
eq-hashtable-ref returns the value associated with key in hashtable. If no value is associated with key in hashtable, eq-hashtable-ref returns default.
(define ht (make-eq-hashtable))
(define p1 (cons 'a 'b))
(define p2 (cons 'a 'b))
(eq-hashtable-set! ht p1 73)
(eq-hashtable-ref ht p1 55) ⇒ 73
(eq-hashtable-ref ht p2 55) ⇒ 55

(eq-hashtable-contains? hashtable key) procedure
returns: #t if an association for key exists in hashtable, #f otherwise
libraries: (chezscheme)

hashtable must be an eq hashtable. key may be any Scheme value.

(define ht (make-eq-hashtable))
(define p1 (cons 'a 'b))
(define p2 (cons 'a 'b))
(eq-hashtable-set! ht p1 73)
(eq-hashtable-contains? ht p1) ⇒ #t
(eq-hashtable-contains? ht p2) ⇒ #f

(eq-hashtable-update! hashtable key procedure default) procedure
returns: unspecified
libraries: (chezscheme)

hashtable must be a mutable eq hashtable. key and default may be any Scheme values. procedure should accept one argument, should return one value, and should not modify hashtable.

eq-hashtable-update! applies procedure to the value associated with key in hashtable, or to default if no value is associated with key in hashtable. If procedure returns, eq-hashtable-update! associates key with the value returned by procedure, replacing the old association, if any.

A version of eq-hashtable-update! that does not verify that it receives arguments of the proper type might be defined as follows.

(define eq-hashtable-update!
  (lambda (ht key proc value)
    (eq-hashtable-set! ht key
      (proc (eq-hashtable-ref ht key value))))))

An implementation may, however, be able to implement eq-hashtable-update! more efficiently by avoiding multiple hash computations and hashtable lookups.

(define ht (make-eq-hashtable))
(eq-hashtable-update! ht 'a
  (lambda (x) (* x 2))
  55)
(eq-hashtable-ref ht 'a 0) ⇒ 110
(eq-hashtable-update! ht 'a
  (lambda (x) (* x 2))
  0)
(eq-hashtable-ref ht 'a 0) ⇒ 220

(eq-hashtable-cell hashtable key default) procedure
returns: a pair (see below)
libraries: (chezscheme)

hashable must be a mutable eq hashtable. key and default may be any Scheme values.

If no value is associated with key in hashtable, eq-hashtable-cell modifies hashtable to associate key with default. It returns a pair whose car is key and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate key with a new value. The key should not be changed.

(define ht (make-eq-hashtable))
(define v (vector 'a 'b 'c))
(define cell (eq-hashtable-cell ht v 3))
cell ⇒ (#(a b c) . 3)
(eq-hashtable-ref ht v 0) ⇒ 3
(set-cdr! cell 4)
(eq-hashtable-ref ht v 0) ⇒ 4

(eq-hashtable-try-atomic-cell hashtable key default) procedure
returns: a pair or #f (see below)
libraries: (chezscheme)

Like eq-hashtable-cell, but safe for use from multiple threads at the same time as long as only this function, eq-hashtable-ref, eq-hashtable-ref-cell, and eq-hashtable-contains? are used on a particular hash table by any thread. To handle certain forms of contention, the result may be #f, in which case the operation might be retried. An even more significant constraint is that the hash table will not be resized interally as needed to provide constant-time behavior. Use eq-hashtable-set! or a similar operation from a single thread (e.g., during a collect-request handler) to allow the opportunity of resizing.

(eq-hashtable-ref-cell hashtable key) procedure
returns: a pair if key is in hashtable, #f otherwise
libraries: (chezscheme)

hashable must be a mutable eq hashtable. key may be any Scheme value.

If key is associated with a value in hashtable, then eq-hashtable-ref-cell returns a pair whose car is key and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate key with a new value. The key in the car field should not be changed.

If key is not in hashtable, then #f is returned.
(define ht (make-eq-hashtable))
(define v (vector 'a 'b 'c))
(eq-hashtable-ref-cell ht v) ⇒ #f
(eq-hashtable-set! ht v 3)
(define cell (eq-hashtable-ref-cell ht v))
cell ⇒ ((#a b c) . 3)
(eq-hashtable-ref ht v 0) ⇒ 3
(set-cdr! cell 4)
(eq-hashtable-ref ht v 0) ⇒ 4

(eq-hashtable-delete! hashtable key) procedure
returns: unspecified
libraries: (chezscheme)

hashtable must be a mutable eq hashtable. key may be any Scheme value.
eq-hashtable-delete! drops any association for key from hashtable.

(define ht (make-eq-hashtable))
(define p1 (cons 'a 'b))
(define p2 (cons 'a 'b))
(eq-hashtable-set! ht p1 73)
(eq-hashtable-contains? ht p1) ⇒ #t
(eq-hashtable-delete! ht p1)
(eq-hashtable-contains? ht p1) ⇒ #f
(eq-hashtable-contains? ht p2) ⇒ #f
(eq-hashtable-delete! ht p2)

(symbol-hashtable? obj) procedure
returns: #t if obj is a symbol hashtable, #f otherwise
libraries: (chezscheme)

A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.

(symbol-hashtable? (make-hashtable symbol-hash eq?)) ⇒ #t
(symbol-hashtable? (make-eq-hashtable)) ⇒ #f

(symbol-hashtable-set! hashtable key value) procedure
returns: unspecified
libraries: (chezscheme)

hashtable must be a mutable symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.) key must be a symbol, and value may be any Scheme value.
symbol-hashtable-set! associates the value value with the key key in hashtable.
(define ht (make-hashtable symbol-hash eq?))
(symbol-hashtable-ref ht 'a #f) ⇒ #f
(symbol-hashtable-set! ht 'a 73)
(symbol-hashtable-ref ht 'a #f) ⇒ 73

(symbol-hashtable-ref hashtable key default) procedure
returns: see below
libraries: (chezscheme)

hashtable must be a symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.) key must be a symbol, and default may be any Scheme value.

symbol-hashtable-ref returns the value associated with key in hashtable. If no value is associated with key in hashtable, symbol-hashtable-ref returns default.

(define ht (make-hashtable symbol-hash eq?))
(define k1 'abcd)
(define k2 'not-abcd)
(symbol-hashtable-set! ht k1 "hi")
(symbol-hashtable-ref ht k1 "bye") ⇒ "hi"
(symbol-hashtable-ref ht k2 "bye") ⇒ "bye"

(symbol-hashtable-contains? hashtable key) procedure
returns: #t if an association for key exists in hashtable, #f otherwise
libraries: (chezscheme)

hashtable must be a symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.) key must be a symbol.

(define ht (make-hashtable symbol-hash eq?))
(define k1 'abcd)
(define k2 'not-abcd)
(symbol-hashtable-set! ht k1 "hi")
(symbol-hashtable-contains? ht k1) ⇒ #t
(symbol-hashtable-contains? ht k2 ) ⇒ #f

(symbol-hashtable-update! hashtable key procedure default) procedure
returns: unspecified
libraries: (chezscheme)

hashtable must be a mutable symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.) key must be a symbol, and default may be any Scheme value. procedure should accept one argument, should return one value, and should not modify hashtable.
symbol-hashtable-update! applies procedure to the value associated with key in hashtable, or to default if no value is associated with key in hashtable. If procedure returns, symbol-hashtable-update! associates key with the value returned by procedure, replacing the old association, if any.

A version of symbol-hashtable-update! that does not verify that it receives arguments of the proper type might be defined as follows.

(define symbol-hashtable-update!  
  (lambda (ht key proc value)  
    (symbol-hashtable-set! ht key  
      (proc (symbol-hashtable-ref ht key value)))))

An implementation may, however, be able to implement symbol-hashtable-update! more efficiently by avoiding multiple hash computations and hashtable lookups.

(define ht (make-hashtable symbol-hash eq?))  
(symbol-hashtable-update! ht 'a  
  (lambda (x) (* x 2))  
  55)  
(symbol-hashtable-ref ht 'a 0) ⇒ 110  
(symbol-hashtable-update! ht 'a  
  (lambda (x) (* x 2))  
  0)  
(symbol-hashtable-ref ht 'a 0) ⇒ 220

(symbol-hashtable-cell hashtable key default) procedure
returns: a pair (see below)
libraries: (chezscheme)

hashtable must be a mutable symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.) key must be a symbol, and default may be any Scheme value.

If no value is associated with key in hashtable, symbol-hashtable-cell modifies hashtable to associate key with default. It returns a pair whose car is key and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate key with a new value. The key should not be changed.

(define ht (make-hashtable symbol-hash eq?))  
(define k 'a-key)  
(define cell (symbol-hashtable-cell ht k 3))  
cell ⇒ (a-key . 3)  
(symbol-hashtable-ref ht k 0) ⇒ 3  
(set-cdr! cell 4)  
(symbol-hashtable-ref ht k 0) ⇒ 4
7.15. Record Types

Chez Scheme extends the Revised 6 Report’s define-record-type syntax in one way, which is that it allows a generative record type to be declared explicitly as such (in a double-negative sort of way) by including a nongenerative clause with #f as the uid, i.e.:

(symbol-hashtable-ref-cell hashtable key) procedure
returns: a pair if key is in hashtable, #f otherwise
libraries: (chezscheme)

hashtable must be a mutable symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.)
key must be a symbol.

If key is associated with a value in hashtable, then it returns a pair whose car is key and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate key with a new value. The key in the car field should not be changed.

If key is not in hashtable, then #f is returned.

(define ht (make-hashtable symbol-hash eq?))
(define k 'a-key)
(symbol-hashtable-ref-cell ht k) ⇒ #f
(symbol-hashtable-set! ht k 3)
(define cell (symbol-hashtable-ref-cell ht k))
cell ⇒ (a-key . 3)
(symbol-hashtable-ref ht k 0) ⇒ 3
(set-cdr! cell 4)
(symbol-hashtable-ref ht k 0) ⇒ 4

(symbol-hashtable-delete! hashtable key) procedure
returns: unspecified
libraries: (chezscheme)

hashtable must be a mutable symbol hashtable. (A symbol hashtable is a hashtable created with hash function symbol-hash and equivalence function eq?, eqv?, equal?, or symbol=?.)
key must be a symbol.

symbol-hashtable-delete! drops any association for key from hashtable.

(define ht (make-hashtable symbol-hash eq?))
(define k1 (gensym))
(define k2 (gensym))
(symbol-hashtable-set! ht k1 73)
(symbol-hashtable-contains? ht k1) ⇒ #t
(symbol-hashtable-delete! ht k1)
(symbol-hashtable-contains? ht k1) ⇒ #f
(symbol-hashtable-contains? ht k2) ⇒ #f
(symbol-hashtable-delete! ht k2)
This can be used in conjunction with the parameter \texttt{require-nongenerative-clause} to catch the accidental use of generative record types while avoiding spurious errors for record types that must be generative. Generative record types are rarely needed and are generally less efficient since a run-time representation of the type is created each time the \texttt{define-record-clause} is evaluated, rather than once at compile (expansion) time.

\begin{verbatim}
require-nongenerative-clause
libraries: (chezscheme)
\end{verbatim}

This parameter holds a boolean value that determines whether \texttt{define-record-type} requires a nongenerative clause. The default value is \#f. The lead-in above describes why one might want to set this to \#t.

### 7.16. Record Equality and Hashing

By default, the \texttt{equal?} primitive compares record instances using \texttt{eq?}, i.e., it distinguishes non-\texttt{eq?} instances even if they are of the same type and have equal contents. A program can override this behavior for instances of a record type (and its subtypes that do not have their own equality procedures) by using \texttt{record-type-equal-procedure} to associate an equality procedure with the record-type descriptor (\texttt{rtd}) that describes the record type.

When comparing two \texttt{eq?} instances, \texttt{equal?} always returns \#t. When comparing two non-\texttt{eq?} instances that share an equality procedure \texttt{equal-proc}, \texttt{equal?} uses \texttt{equal-proc} to compare the instances. Two instances \(x\) and \(y\) share an equality procedure if they inherit an equality procedure from the same point in the inheritance chain, i.e., if \((\texttt{record-equal-procedure } x\ y)\) returns a procedure (\texttt{equal-proc}) rather than \#f. \texttt{equal?} passes \texttt{equal-proc} three arguments: the two instances plus a \texttt{eql?} procedure that should be used for recursive comparison of values within the two instances. Use of \texttt{eql?} for recursive comparison is necessary to allow comparison of potentially cyclic structure. When comparing two non-\texttt{eq?} instances that do not share an equality procedure, \texttt{equal?} returns \#f.

A default equality procedure to be used for all record types (including opaque types) can be specified via the parameter \texttt{default-record-equal-procedure}. The default equality procedure is used only if neither instance’s type has or inherits a type-specific record equality procedure.

Similarly, when the \texttt{equal-hash} primitive hashes a record instance, it defaults to a value that is independent of the record type and contents of the instance. A program can override this behavior for instances of a record type by using \texttt{record-type-hash-procedure} to associate a hash procedure with the record-type descriptor (\texttt{rtd}) that describes the record type. The procedure \texttt{record-hash-procedure} can be used to find the hash procedure for a given record instance, following the inheritance chain. \texttt{equal-hash} passes the hash procedure two arguments: the instance plus a \texttt{hash} procedure that should be used for recursive hashing of
values within the instance. Use of hash for recursive hashing is necessary to allow hashing of potentially cyclic structure and to make the hashing of shared structure more efficient.

A default hash procedure to be used for all record types (including opaque types) can be specified via the parameter default-record-hash-procedure. The default hash procedure is used only if an instance’s type does not have or inherit a type-specific hash procedure.

The following example illustrates the setting of equality and hash procedures.

```lisp
(define-record-type marble
  (nongenerative)
  (fields color quality))

(record-type-equal-procedure (record-type-descriptor marble)) ⇒ #f

(equal? (make-marble 'blue 'medium) (make-marble 'blue 'medium)) ⇒ #f

(equal? (make-marble 'blue 'medium) (make-marble 'blue 'high)) ⇒ #f

; Treat marbles as equal when they have the same color
(record-type-equal-procedure (record-type-descriptor marble)
  (lambda (m1 m2 eq?)
    (eql? (marble-color m1) (marble-color m2))))

(record-type-hash-procedure (record-type-descriptor marble)
  (lambda (m hash)
    (hash (marble-color m))))

(equal? (make-marble 'blue 'medium) (make-marble 'blue 'high)) ⇒ #t

(equal? (make-marble 'red 'high) (make-marble 'blue 'high)) ⇒ #f

(define ht (make-hashtable equal-hash equal?))
(hashtable-set! ht (make-marble 'blue 'medium) "glass")
(hashtable-ref ht (make-marble 'blue 'high) #f) ⇒ "glass"

(define-record-type shooter
  (nongenerative)
  (parent marble)
  (fields size))

(equal? (make-marble 'blue 'medium) (make-shooter 'blue 'large 17)) ⇒ #t

(equal? (make-shooter 'blue 'large 17) (make-marble 'blue 'medium)) ⇒ #t

(hashtable-ref ht (make-shooter 'blue 'high 17) #f) ⇒ "glass"

This example illustrates the application of equality and hash procedures to cyclic record structures.

(define-record-type node
  (nongenerative)
  (fields (mutable left) (mutable right)))

(record-type-equal-procedure (record-type-descriptor node)
  (lambda (x y e?)
    (and
      (e? (node-left x) (node-left y))
      (e? (node-right x) (node-right y))))))
```
(record-type-hash-procedure (record-type-descriptor node)
  (lambda (x hash)
    (+ (hash (node-left x)) (hash (node-right x)) 23)))

(define graph1
  (let ([x (make-node "a" (make-node #f "b"))])
    (node-left-set! (node-right x) x)))

(define graph2
  (let ([x (make-node "a" (make-node (make-node "a" #f) "b"))])
    (node-right-set! (node-left (node-right x)) (node-right x))))

(define graph3
  (let ([x (make-node "a" (make-node #f "c"))])
    (node-left-set! (node-right x) x)))

(equal? graph1 graph2) ⇒ #t
(equal? graph1 graph3) ⇒ #f
(equal? graph2 graph3) ⇒ #f

(define h (make-hashtable equal-hash equal?))
(hashtable-set! h graph1 #t)
(hashtable-ref h graph1 #f) ⇒ #t
(hashtable-ref h graph2 #f) ⇒ #t
(hashtable-ref h graph3 #f) ⇒ #f

(record-type-equal-procedure rtd equal-proc) procedure
returns: unspecified

(record-type-equal-procedure rtd) procedure
returns: equality procedure associated with rtd, if any, otherwise #f
libraries: (chezscheme)

In the first form, equal-proc must be a procedure or #f. If equal-proc is a procedure, a new association between rtd and equal-proc is established, replacing any existing such association. If equal-proc is #f, any existing association between rtd and an equality procedure is dropped.

In the second form, record-type-equal-procedure returns the equality procedure associated with rtd, if any, otherwise #f.

When changing a record type's equality procedure, the record type's hash procedure, if any, should be updated if necessary to maintain the property that it produces the same hash value for any two instances the equality procedure considers equal.
(record-equal-procedure record_1 record_2)  procedure
returns: the shared equality procedure for record_1 and record_2, if there is one, otherwise #f
libraries: (chezscheme)

record-equal-procedure traverses the inheritance chains for both record instances in an attempt to find the most specific type for each that is associated with an equality procedure, if any. If such type is found and is the same for both instances, the equality procedure associated with the type is returned. Otherwise, #f is returned.

(record-type-hash-procedure rtd hash-proc)  procedure
returns: unspecified
(libraries: (chezscheme))

(record-type-hash-procedure rtd)  procedure
returns: hash procedure associated with rtd, if any, otherwise #f
(libraries: (chezscheme))

In the first form, hash-proc must be a procedure or #f. If hash-proc is a procedure, a new association between rtd and hash-proc is established, replacing any existing such association. If hash-proc is #f, any existing association between rtd and a hash procedure is dropped.

In the second form, record-type-hash-procedure returns the hash procedure associated with rtd, if any, otherwise #f.

The procedure hash-proc should accept two arguments, the instance for which it should compute a hash value and a hash procedure to use to compute hash values for arbitrary fields of the instance, and it returns a nonnegative exact integer. A record type’s hash procedure should produce the same hash value for any two instances the record type’s equality procedure considers equal.

(record-hash-procedure record)  procedure
returns: the hash procedure for record, if there is one, otherwise #f
(libraries: (chezscheme))

record-hash-procedure traverses the inheritance chain for the record instance in an attempt to find the most specific type that is associated with a hash procedure, if any. If such type is found, the hash procedure associated with the type is returned. Otherwise, #f is returned.

default-record-equal-procedure  thread parameter
(libraries: (chezscheme))

This parameter determines how two record instances are compared by equal? if neither has a type-specific equality procedure. When the parameter has the value #f (the default), equal? compares the instances with eq?, i.e., there is no attempt at determining structural equivalence. Otherwise, the parameter’s value must be a procedure, and equal? invokes that procedure to compare the instances, passing it three arguments: the two instances
and a procedure that should be used to recursively compare arbitrary values within the instances.

```scheme
default-record-hash-procedure
```

This parameter determines the hash procedure used when `equal-hash` is called on a record instance and the instance does not have a type-specific hash procedure. When the parameter has the value `#f` (the default), `equal-hash` returns a value that is independent of the record type and contents of the instance. Otherwise, the parameter’s value must be a procedure, and `equal-hash` invokes the procedure to compute the instance’s hash value, passing it the record instance and a procedure to invoke to recursively compute hash values for arbitrary values contained within the record. The procedure should return a nonnegative exact integer, and the return value should be the same for any two instances the default equal procedure considers equivalent.

### 7.17. Legacy Record Types

In addition to the Revised\(^6\) Report record-type creation and definition mechanisms, which are described in Chapter 9 of *The Scheme Programming Language, 4th Edition*, Chez Scheme continues to support pre-R6RS mechanisms for creating new data types, or *record types*, with fixed sets of named fields. Many of the procedures described in this section are available only when imported from the `(chezscheme csv7)` library.

Code intended to be portable should use the R6RS mechanism instead.

Records may be defined via the `define-record` syntactic form or via the `make-record-type` procedure. The underlying representation of records and record-type descriptors is the same for the Revised\(^6\) Report mechanism and the alternative mechanism. Record types created by one can be used as parent record types for the other via the procedural mechanisms, though not via the syntactic mechanisms.

The syntactic (`define-record`) interface is the most commonly used interface. Each `define-record` form defines a constructor procedure for records of the new type, a type predicate that returns true only for records of the new type, an access procedure for each field, and an assignment procedure for each mutable field. For example,

```scheme
(define-record point (x y))
```

creates a new `point` record type with two fields, `x` and `y`, and defines the following procedures:

```
(make-point x y)    ; constructor
(point? obj)       ; predicate
(point-x p)        ; accessor for field x
(point-y p)        ; accessor for field y
(set-point-x! p obj) ; mutator for field x
(set-point-y! p obj) ; mutator for field y
```
The names of these procedures follow a regular naming convention by default, but the
programmer can override the defaults if desired. \texttt{define-record} allows the programmer to
control which fields are arguments to the generated constructor procedure and which are
explicitly initialized by the constructor procedure. Fields are mutable by default, but may
be declared immutable. Fields can generally contain any Scheme value, but the internal
representation of each field may be specified, which places implicit constraints on the type
of value that may be stored there. These customization options are covered in the formal
description of \texttt{define-record} later in this section.

The procedural (\texttt{make-record-type}) interface may be used to implement interpreters that
must handle \texttt{define-record} forms. Each call to \texttt{make-record-type} returns a \texttt{record-type
descriptor} representing the record type. Using this record-type descriptor, programs may
generate constructors, type predicates, field accessors, and field mutators dynamically. The
following code demonstrates how the procedural interface might be used to create a similar
point record type and associated definitions.

\begin{verbatim}
(define point (make-record-type "point" '(x y)))
(define make-point (record-constructor point))
(define point? (record-predicate point))
(define point-x (record-field-accessor point 'x))
(define point-y (record-field-accessor point 'y))
(define set-point-x! (record-field-mutator point 'x))
(define set-point-y! (record-field-mutator point 'y))
\end{verbatim}

The procedural interface is more flexible than the syntactic interface, but this flexibility can
lead to less readable programs and compromises the compiler’s ability to generate efficient
code. Programmers should use the syntactic interface whenever it suffices.

A record-type descriptor may also be extracted from an instance of a record type, whether
the record type was produced by \texttt{define-record} or \texttt{make-record-type}, and the extracted
descriptor may also be used to produce constructors, predicates, accessors, and mutators,
with a few limitations noted in the description of \texttt{record-type-descriptor} below. This is
a powerful feature that permits the coding of portable printers and object inspectors. For
example, the printer employs this feature in its default record printer, and the inspector uses
it to allow inspection and mutation of system- and user-defined records during debugging.

A parent record may be specified in the \texttt{define-record} syntax or as an optional argument
to \texttt{make-record-type}. A new record inherits the parent record’s fields, and each instance
of the new record type is considered to be an instance of the parent type as well, so that
accessors and mutators for the parent type may be used on instances of the new type.

Record type definitions may be classified as either generative or nongenerative. A new type
results for each \textit{generative} record definition, while only one type results for all occurrences
of a given \textit{nongenerative} record definition. This distinction is important semantically since
record accessors and setters are applicable only to objects with the same type.

Syntactic (\texttt{define-record}) record definitions are \textit{expand-time generative} by default, which
means that a new record is created when the code is expanded. Expansion happens once
for each form prior to compilation or interpretation, as when it is entered interactively,
loaded from source, or compiled by \texttt{compile-file}. As a result, multiple evaluations of a
single `define-record` form, e.g., in the body of a procedure called multiple times, always produce the same record type.

Separate `define-record` forms usually produce different types, even if the forms are textually identical. The only exception occurs when the name of a record is specified as a generated symbol, or `gensym` (page 170). Multiple copies of a record definition whose name is given by a gensym always produce the same record type; i.e., such definitions are nongenerative. Each copy of the record definition must contain the same fields and field modifiers in the same order; an exception is raised with condition-type `&assertion` when two differing record types with the same generated name are loaded into the same Scheme process.

Procedural (`make-record-type`) record definitions are run-time generative by default. That is, each call to `make-record-type` usually produces a new record type. As with the syntactic interface, the only exception occurs when the name of the record is specified as a gensym, in which case the record type is fully nongenerative.

By default, a record is printed with the syntax

```
#[type-name field ...]
```

where `field ...` are the printed representations of the contents of the fields of the record, and `type-name` is a generated symbol, or `gensym` (page 170), that uniquely identifies the record type. For nongenerative records, `type-name` is the gensym provided by the program. Otherwise, it is a gensym whose “pretty” name (page 170) is the name given to the record by `define-record` or `make-record-type`.

The default printing of records of a given type may be overridden with `record-writer`.

The default syntax may be used as input to the reader as well, as long as the corresponding record type has already been defined in the Scheme session in which the read occurs. The parameter `record-reader` may be used to specify a different name to be recognized by the reader in place of the generated name. Specifying a different name in this manner also changes the name used when the record is printed. This reader extension is disabled in an input stream after `#!r6rs` has been seen by the reader, unless `#!chezscheme` has been seen more recently.

The mark (`#n=`) and reference (`#n#`) syntaxes may be used within the record syntax, with the result of creating shared or cyclic structure as desired. All cycles must be resolvable, however, without mutation of an immutable record field. That is, any cycle must contain at least one pointer through a mutable field, whether it is a mutable record field or a mutable field of a built-in object type such as a pair or vector.

When the parameter `print-record` is set to `#f`, records are printed using the simpler syntax

```
<record of type name>
```

where `name` is the “pretty” name of the record (not the full gensym) or the reader name first assigned to the record type.
A `define-record` form is a definition and may appear anywhere and only where other definitions may appear.

`define-record` creates a new record type containing a specified set of named fields and defines a set of procedures for creating and manipulating instances of the record type.

`name` must be an identifier. If `name` is a generated symbol (gensym), the record definition is nongenerative, otherwise it is `expand-time generative`. (See the discussion of generativity earlier in this section.)

Each `fld` must be an identifier `field-name`, or it must take the form

```
(class type field-name)
```

where `class` and `type` are optional and `field-name` is an identifier. `class`, if present, must be the keyword `immutable` or the keyword `mutable`. If the `immutable` class specifier is present, the field is immutable; otherwise, the field is mutable. `type`, if present, specifies how the field is represented, as described below.

- `ptr` any Scheme object
- `scheme-object` same as `ptr`
- `int` a C int
- `unsigned` a C unsigned int
- `short` a C short
- `unsigned-short` a C unsigned short
- `long` a C long
- `unsigned-long` a C unsigned long
- `iptr` a signed integer the size of a `ptr`
- `uptr` an unsigned integer the size of a `ptr`
- `float` a C float
- `double` a C double
- `integer-8` an eight-bit signed integer
- `unsigned-8` an eight-bit unsigned integer
- `integer-16` a 16-bit signed integer
- `unsigned-16` a 16-bit unsigned integer
- `integer-32` a 32-bit signed integer
- `unsigned-32` a 32-bit unsigned integer
- `integer-64` a 64-bit signed integer
- `unsigned-64` a 64-bit unsigned integer
- `single-float` a 32-bit single floating point number
- `double-float` a 64-bit double floating point number

If a type is specified, the field can contain objects only of the specified type. If no type is specified, the field is of type `ptr`, meaning that it can contain any Scheme object.

The field identifiers name the fields of the record. The values of the `n` fields described by
fld_1 \ldots \text{ are specified by the } n \text{ arguments to the generated constructor procedure. The}
\text{ values of the remaining fields, } fld_2 \ldots , \text{ are given by the corresponding expressions, } init \ldots .
\text{ Each } init \text{ is evaluated within the scope of the set of field names given by } fld_1 \ldots \text{ and each}
\text{ field in } fld_2 \ldots \text{ that precedes it, as if within a } \textbf{let*} \text{ expression. Each of these field names}
\text{ is bound to the value of the corresponding field during initialization.}
\text{ If } parent \text{ is present, the record type named by } parent \text{ is the parent of the record. The}
\text{ new record type inherits each of the parent record’s fields, and records of the new type are}
\text{ considered records of the parent type. If } parent \text{ is not present, the parent record type is a}
\text{ base record type with no fields.}
\text{ The following procedures are defined by } \textbf{define-record}:$
\text{ \begin{itemize}
\item a constructor procedure whose name is } \textit{make-name},
\item a type predicate whose name is } \textit{name?},
\item an access procedure whose name is } \textit{name-fieldname} \text{ for each noninherited field, and}
\item an assignment procedure whose name is } \textit{set-name-fieldname!} \text{ for each noninherited}
\text{ mutable field.}
\end{itemize}$
\text{ If no parent record type is specified, the constructor behaves as if defined as}
$(\textbf{define } \textit{make-name}\n(\lambda (id\_1 \ldots)
(\textbf{let*} ([id\_2 \textit{init}] \ldots)
body)))$
\text{ where } id\_1 \ldots \text{ are the names of the fields defined by } fld\_1 \ldots , \text{ id\_2 \ldots \ are the names of}
\text{ the fields defined by } fld\_2 \ldots , \text{ and body builds the record from the values of the identifiers}
\text{ id\_1 \ldots \ and id\_2 \ldots.}$
\text{ If a parent record type is specified, the parent arguments appear first, and the parent fields}
\text{ are inserted into the record before the child fields.}
\text{ The options } opt \ldots \text{ control the selection of names of the generated constructor, predicate,}
\text{ accessors, and mutators.}$
$(\textbf{constructor } id)$
$(\textbf{predicate } id)$
$(\textbf{prefix } string)$
\text{ The option } (\textbf{constructor } id) \text{ causes the generated constructor’s name to be } id \text{ rather than}
\textit{make-name}. \text{ The option } (\textbf{predicate } id) \text{ likewise causes the generated predicate’s name to}
\text{ be } id \text{ rather than } name?. \text{ The option } (\textbf{prefix } string) \text{ determines the prefix to be used in}
\text{ the generated accessor and mutator names in place of } name-.$
\text{ If no options are needed, the third subexpression, } (opt \ldots), \text{ may be omitted. If no options}
\text{ and no fields other than those initialized by the arguments to the constructor procedure are}
\text{ needed, both the second and third subexpressions may be omitted. If options are specified,}
\text{ the second subexpression must be present, even if it contains no field specifiers.}$
\text{ Here is a simple example with no inheritance and no options.}$
(define-record marble (color quality))
(define x (make-marble 'blue 'medium))
(marble? x) ⇒ #t
(pair? x) ⇒ #f
(vector? x) ⇒ #f
(marble-color x) ⇒ blue
(marble-quality x) ⇒ medium
(set-marble-quality! x 'low)
(marble-quality x) ⇒ low

(define-record marble ((immutable color) (mutable quality))
    (((mutable shape) (if (eq? quality 'high) 'round 'unknown))))
(marble-shape (make-marble 'blue 'high)) ⇒ round
(marble-shape (make-marble 'blue 'low)) ⇒ unknown
(define x (make-marble 'blue 'high))
(set-marble-quality! x 'low)
(marble-shape x) ⇒ round
(set-marble-shape! x 'half-round)
(marble-shape x) ⇒ half-round
The following example illustrates inheritance.

```
(define-record shape (x y))
(define-record point shape ())
(define-record circle shape (radius))

(define a (make-point 7 -3))
(shape? a) ⇒ #t
(point? a) ⇒ #t
(circle? a) ⇒ #f

(shape-x a) ⇒ 7
(set-shape-y! a (- (shape-y a) 1))
(shape-y a) ⇒ -4

(define b (make-circle 7 -3 1))
(shape? b) ⇒ #t
(point? b) ⇒ #f
(circle? b) ⇒ #t

(circle-radius b) ⇒ 1
(circle-radius a) ⇒ exception: not of type circle
```

This example demonstrates the use of options:

```
(define-record pair (car cdr)
  ()
  ((constructor cons)
   (prefix "")))

(define x (cons 'a 'b))
(car x) ⇒ a
(cdr x) ⇒ b
(pair? x) ⇒ #t

(pair? '(a b c)) ⇒ #f
x ⇒ #[#{pair bdhav1bwafxyss1-a} a b]
```

This example illustrates the use a specified reader name, immutable fields, and the graph mark and reference syntax.

```
(define-record triple ((immutable x1) (mutable x2) (immutable x3)))
(record-reader 'triple (type-descriptor triple))

(let ([t '#[triple #1=(1 2) (3 4) #1#]])
  (eq? (triple-x1 t) (triple-x3 t))) ⇒ #t
(let ([x '#(1 2) . #[triple #1# b c]])
  (eq? (car x) (triple-x1 (cdr x)))) ⇒ #t
```
Cycles established with the mark and reference syntax can be resolved only if a mutable record field or mutable location of some other object is involved the cycle, as in the last two examples above. An exception is raised with condition type \texttt{lexical} if only immutable fields are involved.

\[
'\texttt{#1=\texttt{\{triple \#1\# (3 4) \#1=(1 2)\}}} \; \Rightarrow \; \texttt{exception}
\]

The following example demonstrates the use of nongenerative record definitions.

```scheme
(module A (point-disp)
  (define-record #{point bdhavklbwafyss1-b} (x y))
  (define square (lambda (x) (* x x)))
  (define point-disp
    (lambda (p1 p2)
      (sqrt (+ (square (- (point-x p1) (point-x p2)))
                (square (- (point-y p1) (point-y p2)))))))

(module B (base-disp)
  (define-record #{point bdhavklbwafyss1-b} (x y))
  (import A)
  (define base-disp
    (lambda (p)
      (point-disp (make-point 0 0) p))))

(let ()
  (import B)
  (define-record #{point bdhavklbwafyss1-b} (x y))
  (base-disp (make-point 3 4))) \Rightarrow 5
```

This works even if the different program components are loaded from different source files or are compiled separately and loaded from different object files.

| predicate       | syntax
|-----------------|-------|
| prefix          | syntax
| constructor     | syntax
| libraries: (chezscheme)

These identifiers are auxiliary keywords for \texttt{define-record}. It is a syntax violation to reference these identifiers except in contexts where they are recognized as auxiliary keywords. \texttt{mutable} and \texttt{immutable} are also auxiliary keywords for \texttt{define-record}, shared with the Revised\textsuperscript{6} Report \texttt{define-record-type}. 
7. Operations on Objects

(type-descriptor name)  syntax returns: the record-type descriptor associated with name libraries: (chezscheme)

name must name a record type defined by define-record or define-record-type. This form is equivalent to the Revised\textsuperscript{6} Report record-type-descriptor form.

The record-type descriptor is useful for overriding the default read and write syntax using record-reader and record-writer and may also be used with the procedural interface routines described later in this section.

(define-record frob ())(type-descriptor frob) ⇒ #<record type frob>

(record-reader name) procedure returns: the record-type descriptor associated with name

(record-reader rtd) procedure returns: the first name associated with rtd

(record-reader name rtd) procedure returns: unspecified

(record-reader name #f) procedure returns: unspecified

(record-reader rtd #f) procedure returns: unspecified

libraries: (chezscheme)

name must be a symbol, and rtd must be a record-type descriptor.

With one argument, record-reader is used to retrieve the record type associated with a name or name associated with a record type. If no association has been created, record-reader returns #f

With arguments name and rtd, record-reader registers rtd as the record-type descriptor to be used whenever the read procedure encounters a record named by name and printed in the default record syntax.

With arguments name and #f, record-reader removes any association for name to a record-type descriptor. Similarly, with arguments rtd and #f, record-reader removes any association for rtd to a name.

(define-record marble (color quality))(define m (make-marble 'blue 'perfect))
m ⇒ #[(#{marble bdhav1bwafxyss1-c} blue perfect]

(record-reader (type-descriptor marble)) ⇒ #f

(record-reader 'marble) ⇒ #f

(record-reader 'marble (type-descriptor marble))(marble-color '#[marble red miserable]) ⇒ red
7.17. Legacy Record Types

(record-reader (type-descriptor marble)) ⇒ marble
(record-reader 'marble) ⇒ #<record type marble>

(record-reader (type-descriptor marble) #f)
(record-reader (type-descriptor marble)) ⇒ #f
(record-reader 'marble) ⇒ #f

(record-reader 'marble (type-descriptor marble))
(record-reader 'marble #f)
(record-reader (type-descriptor marble)) ⇒ #f
(record-reader 'marble) ⇒ #f

The introduction of a record reader also changes the default printing of records. The printer always chooses the reader name first assigned to the record, if any, in place of the unique record name, as this continuation of the example above demonstrates.

(record-reader 'marble (type-descriptor marble))
(make-marble 'pink 'splendid) ⇒ #[marble pink splendid]

(record-writer rtd)

returns: the record writer associated with rtd

(record-writer rtd procedure)

returns: unspecified

libraries: (chezscheme)

rtd must be a record-type descriptor, and procedure should accept three arguments, as described below.

When passed only one argument, record-writer returns the record writer associated with rtd, which is initially the default record writer for all records. The default print method prints all records in a uniform syntax that includes the generated name for the record and the values of each of the fields, as described in the introduction to this section.

When passed two arguments, record-writer establishes a new association between rtd and procedure so that procedure will be used by the printer in place of the default printer for records of the given type. The printer passes procedure three arguments: the record r, a port p, and a procedure wr that should be used to write out the values of arbitrary Scheme objects that the print method chooses to include in the printed representation of the record, e.g., values of the record’s fields.

(define-record marble (color quality))
(define m (make-marble 'blue 'medium))

m ⇒ #[#{marble bdhav1bwafxyss1-d} blue medium]

(record-writer (type-descriptor marble)
  (lambda (r p wr)
    (display "#" p)
    (wr (marble-quality r) p)
    (display " quality " p))
(wr (marble-color r) p)
(display " marble>" p)))

⇒ #<medium quality blue marble>

The record writer is used only when print-record is true (the default). When the parameter print-record is set to #f, records are printed using a compressed syntax that identifies only the type of record.

(parameterize ([print-record #f])
  (format "-s" m)) ⇒ "#<record of type marble>"

A print method may be called more than once during the printing of a single record to support cycle detection and graph printing (see print-graph), so print methods that perform side effects other than printing to the given port are discouraged. Whenever a print method is called more than once during the printing of a single record, in all but one call, a generic “bit sink” port is used to suppress output automatically so that only one copy of the object appears on the actual port. In order to avoid confusing the cycle detection and graph printing algorithms, a print method should always produce the same printed representation for each object. Furthermore, a print method should normally use the supplied procedure wr to print subobjects, though atomic values, such as strings or numbers, may be printed by direct calls to display or write or by other means.

(let ()
  (define-record ref () ((contents 'nothing)))
  (record-writer (type-descriptor ref)
    (lambda (r p wr)
      (display "<" p)
      (wr (ref-contents r) p)
      (display ">" p)))
  (let ([ref-lexive (make-ref)])
    (set-ref-contents! ref-lexive ref-lexive)
    ref-lexive)) ⇒ #0=<#0#>

Print methods need not be concerned with handling nonfalse values of the parameters print-level. The printer handles print-level automatically even when user-defined print procedures are used. Since records typically contain a small, fixed number of fields, it is usually possible to ignore nonfalse values of print-length as well.

(print-level 3)
(let ()
  (define-record ref () ((contents 'nothing)))
  (record-writer (type-descriptor ref)
    (lambda (r p wr)
      (display "<" p)
      (wr (ref-contents r) p)
      (display ">" p)))
  (let ([ref-lexive (make-ref)])
    (set-ref-contents! ref-lexive ref-lexive)
    ref-lexive)) ⇒ <<<#[..]>>>
7.17. Legacy Record Types

<table>
<thead>
<tr>
<th>print-record</th>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

This parameter controls the printing of records. If set to true (the default) the record writer associated with a record type is used to print records of that type. If set to false, all records are printed with the syntax `#<record of type name>`, where `name` is the name of the record type as returned by `record-type-name`.

\[
\text{(make-record-type type-name fields)}
\]

<table>
<thead>
<tr>
<th>procedure</th>
</tr>
</thead>
</table>

returns: a record-type descriptor for a new record type

libraries: (chezscheme)

make-record-type creates a new data type and returns a record-type descriptor, a value representing the new data type. The new type is disjoint from all others.

If present, `parent-rtd` must be a record-type descriptor.

type-name must be a string or gensym. If type-name is a string, a new record type is generated. If type-name is a gensym, a new record type is generated only if one with the same gensym has not already been defined. If one has already been defined, the parent and fields must be identical to those of the existing record type, and the existing record type is used. If the parent and fields are not identical, an exception is raised with condition-type &assertion.

fields must be a list of field descriptors, each of which describes one field of instances of the new record type. A field descriptor is either a symbol or a list in the following form:

\[
\text{(class type field-name)}
\]

where class and type are optional. field-name must be a symbol. class, if present, must be the symbol immutable or the symbol mutable. If the immutable class-specifier is present, the field is immutable; otherwise, the field is mutable. type, if present, specifies how the field is represented. The types are the same as those given in the description of define-record on page 195.

If a type is specified, the field can contain objects only of the specified type. If no type is specified, the field is of type ptr, meaning that it can contain any Scheme object.

The behavior of a program that modifies the string type-name or the list fields or any of its sublists is unspecified.

The record-type descriptor may be passed as an argument to any of the Revised\(^6\) Report procedures

- record-constructor,
- record-predicate,
- record-accessor, and
- record-mutator,

or to the Chez Scheme variants
7. Operations on Objects

- record-constructor,
- record-field-accessor, and
- record-field-mutator

to obtain procedures for creating and manipulating records of the new type.

```
(define marble
  (make-record-type "marble"
    '(color quality)
    (lambda (r p wr)
      (display "#<" p)
      (wr (marble-quality r) p)
      (display " quality " p)
      (wr (marble-color r) p)
      (display " marble>" p))))

(define make-marble
  (record-constructor marble))

(define marble?
  (record-predicate marble))

(define marble-color
  (record-field-accessor marble 'color))

(define marble-quality
  (record-field-accessor marble 'quality))

(define set-marble-quality!
  (record-field-mutator marble 'quality))

(define x (make-marble 'blue 'high))
(marble? x) ⇒ #t
(marble-quality x) ⇒ high
(set-marble-quality! x 'low)
(marble-quality x) ⇒ low
x ⇒ #<low quality blue marble>
```

The order in which the fields appear in fields is important. While field names are generally distinct, it is permissible for one field name to be the same as another in the list of fields or the same as an inherited name. In this case, field ordinals must be used to select fields in calls to record-field-accessor and record-field-mutator. Ordinals range from zero through one less than the number of fields. Parent fields come first, if any, followed by the fields in fields, in the order given.

```
(define r1 (make-record-type "r1" '(t t)))
(define r2 (make-record-type r1 "r2" '(t)))
(define r3 (make-record-type r2 "r3" '(t t t)))

(define x ((record-constructor r3) 'a 'b 'c 'd 'e 'f))
((record-field-accessor r3 0) x) ⇒ a
((record-field-accessor r3 2) x) ⇒ c
((record-field-accessor r3 4) x) ⇒ e
((record-field-accessor r3 't) x) ⇒ unspecified
```
7.17. Legacy Record Types

(record-constructor rcd) procedure  
(record-constructor rtd) procedure

returns: a constructor for records of the type represented by rtd  
libraries: (chezscheme)

Like the Revised\textsuperscript{6} Report version of this procedure, this procedure may be passed a record-constructor descriptor, rcd, which determines the behavior of the constructor. It may also be passed a record-type descriptor, rtd, in which case the constructor accepts as many arguments as there are fields in the record; these arguments are the initial values of the fields in the order given when the record-type descriptor was created.

(record-field-accessor rtd field-id) procedure  
returns: an accessor for the identified field  
libraries: (chezscheme csv7)

rtd must be a record-type descriptor, field-id must be a symbol or field ordinal, i.e., a nonnegative exact integer less than the number of fields of the given record type. The specified field must be accessible.

The generated accessor expects one argument, which must be a record of the type represented by rtd. It returns the contents of the specified field of the record.

(record-field-accessible? rtd field-id) procedure  
returns: \texttt{#t} if the specified field is accessible, otherwise \texttt{#f}  
libraries: (chezscheme csv7)

rtd must be a record-type descriptor, field-id must be a symbol or field ordinal, i.e., a nonnegative exact integer less than the number of fields of the given record type.

The compiler is free to eliminate a record field if it can prove that the field is not accessed. In making this determination, the compiler is free to ignore the possibility that an accessor might be created from a record-type descriptor obtained by calling record-type-descriptor on an instance of the record type.

(record-field-mutator rtd field-id) procedure  
returns: a mutator for the identified field  
libraries: (chezscheme csv7)

rtd must be a record-type descriptor, field-id must be a symbol or field ordinal, i.e., a nonnegative exact integer less than the number of fields of the given record type. The specified field must be mutable.

The mutator expects two arguments, r and obj. r must be a record of the type represented by rtd. obj must be a value that is compatible with the type declared for the specified field when the record-type descriptor was created. obj is stored in the specified field of the record.
(record-field-mutable? rtd field-id)  
procedure
returns: #t if the specified field is mutable, otherwise #f
libraries: (chezscheme csv7)

rtd must be a record-type descriptor, field-id must be a symbol or field ordinal, i.e., a nonnegative exact integer less than the number of fields of the given record type.

Any field declared immutable is immutable. In addition, the compiler is free to treat a field as immutable if it can prove that the field is never assigned. In making this determination, the compiler is free to ignore the possibility that a mutator might be created from a record-type descriptor obtained by calling record-type-descriptor on an instance of the record type.

(record-type-name rtd)  
procedure
returns: the name of the record-type represented by rtd
libraries: (chezscheme csv7)

rtd must be a record-type descriptor.

The name is a always a string. If a gensym is provided as the record-type name in a define-record form or make-record-type call, the result is the “pretty” name of the gensym (see 7.11).

(record-type-name (make-record-type "empty" '())) ⇒ "empty"

(define-record #{point bdhavk1bwafxyss1-b} (x y))
(define p (type-descriptor #{point bdhavk1bwafxyss1-b}))
(record-type-name p) ⇒ "point"

(record-type-symbol rtd)  
procedure
returns: the generated symbol associated with rtd
libraries: (chezscheme csv7)

rtd must be a record-type descriptor.

(define e (make-record-type "empty" '()))
(record-type-symbol e) ⇒ #{empty bdhavk1bwafxyss1-e}

(define-record #{point bdhavk1bwafxyss1-b} (x y))
(define p (type-descriptor #{point bdhavk1bwafxyss1-b}))
(record-type-symbol p) ⇒ #{point bdhavk1bwafxyss1-b}

(record-type-field-names rtd)  
procedure
returns: a list of field names of the type represented by rtd
libraries: (chezscheme csv7)

rtd must be a record-type descriptor. The field names are symbols.
See also the Revised\textsuperscript{6} Report version of this procedure (exported from the \texttt{(chezscheme)} library) which returns a vector.

\begin{verbatim}
(define-record triple ((immutable x1) (mutable x2) (immutable x3)))
(record-type-field-names (type-descriptor triple)) ⇒ (x1 x2 x3)
\end{verbatim}

\begin{verbatim}
(\texttt{record-type-field-decls rtd}) \textbf{procedure}
\end{verbatim}

\textbf{returns}: a list of field declarations of the type represented by \texttt{rtd}

\textbf{libraries}: \texttt{(chezscheme csv7)}

\texttt{rtd} must be a record-type descriptor. Each field declaration has the following form:

\begin{verbatim}
(class type field-name)
\end{verbatim}

where \texttt{class}, \texttt{type}, and \texttt{field-name} are as described under \texttt{make-record-type}.

\begin{verbatim}
(define-record shape (x y))
(define-record circle shape (radius))
\end{verbatim}

\begin{verbatim}
(record-type-field-decls
 (type-descriptor circle)) ⇒ ((mutable ptr x)
                               (mutable ptr y)
                               (mutable ptr radius))
\end{verbatim}

\begin{verbatim}
(\texttt{record? obj}) \textbf{procedure}
\end{verbatim}

\textbf{returns}: \#t if \texttt{obj} is a record, otherwise \#f

\begin{verbatim}
(\texttt{record? obj rtd}) \textbf{procedure}
\end{verbatim}

\textbf{returns}: \#t if \texttt{obj} is a record of the given type, otherwise \#f

\textbf{libraries}: \texttt{(chezscheme)}

If present, \texttt{rtd} must be a record-type descriptor.

A record is “of the given type” if it is an instance of the record type or one of its ancestors.

The predicate generated by \texttt{record-predicate} for a record-type descriptor \texttt{rtd} is equivalent to the following.

\begin{verbatim}
(l lambda (x) (record? x rtd))
\end{verbatim}

\begin{verbatim}
(\texttt{record-instance? obj rtd}) \textbf{procedure}
\end{verbatim}

\textbf{returns}: \#t if \texttt{obj} is a record of the given type, otherwise \#f

\textbf{libraries}: \texttt{(chezscheme)}

\texttt{obj} must be a record, and \texttt{rtd} must be a record-type descriptor.

The result is the same as for a two-argument \texttt{record?} call, but \texttt{obj} is constrained to be a record. In unsafe mode, \texttt{record-instance?} might be faster than \texttt{record?}. 

7. Operations on Objects

(record-type-descriptor rec)  
returns: the record-type descriptor of rec  
libraries: (chezscheme csv7)

rec must be a record. This procedure is intended for use in the definition of portable printers  
and debuggers. For records created with make-record-type, it may not be the same as the  
descriptor returned by make-record-type. See the comments about field accessibility and  
mutability under record-field-accessible? and record-field-mutable? above.

This procedure is equivalent to the Revised⁶ Report record-rtd procedure.

(define rtd (make-record-type "frob" '(blit blat)))  
rtd => #<record type frob>  
(define x ((record-constructor rtd) 1 2))  
(record-type-descriptor x) => #<record type frob>  
(eq? (record-type-descriptor x) rtd) => unspecified

(make-record-type-descriptor name parent uid s? o? fields)  
returns: a record-type descriptor for a new record type  
libraries: (chezscheme)

Like the Revised⁶ Report version of this procedure, but fields is also allowed to be a pair  
of non-negative integers, in which case the new record type has anonymous fields. The  
car of fields is a field count, and it is added to any fields present in parent to determine  
the record type’s total number of fields. The cdr of fields must be an exact non-negative  
integer that is treated as a bit array; a 1 bit indicates the the corresponding field among  
new fields is mutable. The total number of fields in a record type must be a fixnum.

If parent is a record type descriptor, it must also have anonymous fields. The resulting  
anonymous-field record type can only be the parent of a record type with anonymous fields.

When a function like record-type-field-names is applied to an anonymous-field record  
type, the field names are all reported as field.

(record-type-has-named-fields? rtd)  
returns: a boolean indicating whether rtd has named fields  
libraries: (chezscheme)

rtd must be a record-type descriptor.

7.18. Procedures

(procedure-arity-mask proc)  
returns: an exact integer bitmask identifying the accepted argument counts of proc  
libraries: (chezscheme)

The bitmask is represented as two’s complement number with the bit at each index n set  
if and only if proc accepts n arguments.
The two’s complement encoding implies that if \( \text{proc} \) accepts \( n \) or more arguments, the encoding is a negative number, since all the bits from \( n \) and up are set. For example, if \( \text{proc} \) accepts any number of arguments, the two’s complement encoding of all bits set is \(-1\).

\[
\begin{align*}
\text{(procedure-arity-mask (lambda () 'none))} & \Rightarrow 1 \\
\text{(procedure-arity-mask car)} & \Rightarrow 2 \\
\text{(procedure-arity-mask (case-lambda [[() 'none] [(x) x]])}) & \Rightarrow 3 \\
\text{(procedure-arity-mask (lambda x x))} & \Rightarrow -1 \\
\text{(procedure-arity-mask (case-lambda [[() 'none] [(x y . z) x]])}) & \Rightarrow -3 \\
\text{(procedure-arity-mask (case-lambda))} & \Rightarrow 0 \\
\text{(logbit? 1 (procedure-arity-mask pair?))} & \Rightarrow \#t \\
\text{(logbit? 2 (procedure-arity-mask pair?))} & \Rightarrow \#f \\
\text{(logbit? 2 (procedure-arity-mask cons))} & \Rightarrow \#t
\end{align*}
\]

\[
\begin{align*}
\text{(make-wrapper-procedure proc arity-mask data)} & \quad \text{procedure} \\
\text{(make-arity-wrapper-procedure proc arity-mask data)} & \quad \text{procedure} \\
\text{returns: a procedure that behaves like proc, but with the given arity-mask} \\
\text{libraries: (chezscheme)}
\end{align*}
\]

\( \text{proc} \) must be a procedure, and \( \text{arity-mask} \) must be an exact integer representing an arity mask in the sense of \( \text{procedure-arity-mask} \).

The resulting procedure behaves the same as \( \text{proc} \), except that \( \text{procedure-arity-mask} \) on the result procedure returns \( \text{arity-mask} \). When the result of \( \text{make-arity-wrapper-procedure} \) is called, the given arguments are compared to the given arity mask, and an error is reported if the argument count does not match. The result of \( \text{make-wrapper-procedure} \), in contrast, does not enforce the given arity mask.

The \( \text{data} \) argument can be any value, and it can be retrieved from the result procedure with \( \text{wrapper-procedure-data} \).

\[
\begin{align*}
\text{(define vector3 (make-wrapper-procedure vector 8 #f))} \\
\text{(procedure-arity-mask vector)} & \Rightarrow -1 \\
\text{(procedure-arity-mask vector3)} & \Rightarrow 8 \\
\text{(vector3 1 2 3)} & \Rightarrow \#(1 2 3) \\
\text{(vector3 1 2)} & \Rightarrow \#(1 2) \\
\text{(define vector3/check (make-arity-wrapper-procedure vector 8 #f))} \\
\text{(vector3/check 1 2 3)} & \Rightarrow \#(1 2 3) \\
\text{(vector3/check 1 2)} & \Rightarrow \text{exception}
\end{align*}
\]

\[
\begin{align*}
\text{(wrapper-procedure? obj)} & \quad \text{procedure} \\
\text{returns: \#t if obj is a wrapper procedure, \#f otherwise} \\
\text{libraries: (chezscheme)}
\end{align*}
\]

Determines whether \( \text{obj} \) is a wrapper procedure produced by either \( \text{make-wrapper-procedure} \) or \( \text{make-arity-wrapper-procedure} \).
(wrapper-procedure? vector) ; => #f
(define vector3 (make-wrapper-procedure vector 8 #f))
(wrapper-procedure? vector3) ; => #t

(wrapper-procedure-procedure w-proc) procedure
returns: the procedure wrapped by the wrapper procedure proc
libraries: (chezscheme)

w-proc must be a wrapper procedure produced by either make-wrapper-procedure or make-arity-wrapper-procedure.

(define vector3 (make-wrapper-procedure vector 8 'my-data))
(wrapper-procedure-procedure vector3) ; => #<procedure vector>

(wrapper-procedure-data w-proc) procedure
returns: the data stored with the wrapper procedure proc
libraries: (chezscheme)

w-proc must be a wrapper procedure produced by either make-wrapper-procedure or make-arity-wrapper-procedure.

(define vector3 (make-wrapper-procedure vector 8 'my-data))
(wrapper-procedure-data vector3) ; => 'my-data

(set-wrapper-procedure-data! w-proc data) procedure
returns: unspecified
libraries: (chezscheme)

w-proc must be a wrapper procedure produced by either make-wrapper-procedure or make-arity-wrapper-procedure.
Changes the data stored in w-proc to data.

(define vector3 (make-wrapper-procedure vector 8 'my-data))
(wrapper-procedure-data vector3) ; => 'my-data
(set-wrapper-procedure-data! vector3 'my-new-data)
(wrapper-procedure-data vector3) ; => 'my-new-data

(set-wrapper-procedure-procedure! w-proc proc) procedure
returns: unspecified
libraries: (chezscheme)

w-proc must be a wrapper procedure produced by either make-wrapper-procedure or make-arity-wrapper-procedure, and proc must be a procedure.
Changes w-proc so that it behaves the same as proc, leaving the results of (procedure-arity-mask w-proc) and (wrapper-procedure-data w-proc) unchanged.
(define vector3 (make-wrapper-procedure vector 8 'my-data))
(vector3 1 2 3) ; => #(1 2 3)
(set-wrapper-procedure-procedure! vector3 list)
(vector3 1 2 3) ; => (1 2 3)

(procedure-known-single-valued? proc);

procedure

returns: a boolean indicating whether proc is known to always produce a single value

libraries: (chezscheme)

Returns an approximate classification of proc as always having a single result value or not. The result may be #f for a procedure that always returns a single value, but with an implementation that was too complex for the compiler to prove that fact. The result is #t only for a procedure that always produces a single result value.
8. Numeric Operations

This chapter describes Chez Scheme extensions to the standard set of operations on numbers. See Chapter 6 of The Scheme Programming Language, 4th Edition or the Revised Report on Scheme for a description of standard operations on numbers.

Chez Scheme supports the full set of Scheme numeric datatypes, including exact and inexact integer, rational, real, and complex numbers. A variety of representations are used to support these datatypes:

* **Fixnums** represent exact integers in the fixnum range (see most-negative-fixnum and most-positive-fixnum). The length of a string, vector, or fxvector is constrained to be a fixnum.

* **Bignums** represent arbitrary-precision exact integers outside of the fixnum range.

* **Ratnums** represent arbitrary-precision exact rational numbers. Each ratnum contains an exact integer (fixnum or bignum) numerator and an exact integer denominator. Ratios are always reduced to lowest terms and never have a denominator of one or a numerator of zero.

* **Flonums** represent inexact real numbers. Flonums are IEEE 64-bit floating-point numbers. (Since flonums cannot represent irrational numbers, all inexact real numbers are actually rational, although they may approximate irrational quantities.)

* **Exact complexnums** represent exact complex numbers. Each exact complexnum contains an exact rational (fixnum, bignum, or ratnum) real part and an exact rational imaginary part.

* **Inexact complexnums** represent inexact complex numbers. Each inexact complexnum contains a flonum real part and a flonum imaginary part.

Most numbers can be represented in only one way; however, real numbers are sometimes represented as inexact complex numbers with imaginary component equal to zero.

Chez Scheme extends the syntax of numbers with arbitrary radices from two through 36, nondecimal floating-point and scientific notation, and printed representations for IEEE infinities and NANs. (NAN stands for “not-a-number.”)

Arbitrary radices are specified with the prefix #n, where n ranges from 2 through 36. Digits beyond 9 are specified with the letters (in either upper or lower case) a through z. For example, #2r101 is 5_{10}, and #36rZ is 35_{10}.

For higher radices, an ambiguity arises between the interpretation of certain letters, e.g., e, as digits or exponent specifiers; in such cases, the letter is assumed to be a digit. For
example, the $e$ in $\#x3.2e5$ is interpreted as a digit, not as an exponent marker, whereas in $3.2e5$ it is treated as an exponent marker.

IEEE infinities are printed as $+\text{inf}.0$ and $-\text{inf}.0$, while IEEE NANs are printed as $+\text{nan}.0$ or $-\text{nan}.0$. ($+\text{nan}.0$ is used on output for all NANs.)

$$
\begin{align*}
(/ \ 1.0 \ 0.0) & \Rightarrow +\text{inf}.0 \\
(/ \ 1.0 \ -0.0) & \Rightarrow -\text{inf}.0 \\
(/ \ 0.0 \ 0.0) & \Rightarrow +\text{nan}.0 \\
(/ \ +\text{inf}.0 \ -\text{inf}.0) & \Rightarrow +\text{nan}.0
\end{align*}
$$

The first section of this chapter describes type-specific numeric type predicates. Sections 8.2 through 8.4 describe fast, type-specific numeric operations on fixnums, flonums, and inexact complex numbers (flonums and/or inexact complexnums). The fixnum-specific versions should be used only when the programmer is certain that the operands and results (where appropriate) will be fixnums, i.e., integers in the range (most-negative-fixnum) to (most-positive-fixnum), inclusive. The flonum-specific versions should be used only when the inputs and outputs (where appropriate) are certain to be flonums. The mixed flonum/complexnum versions should be used only when the inputs are certain to be either flonums or inexact complexnums. Section 8.5 describes operations, both arbitrary precision and fixnum-specific, that allow exact integers to be treated as sets or sequences of bits. Random number generation is covered Section 8.6 and miscellaneous numeric operations are covered in the Section 8.7.

### 8.1. Numeric Type Predicates

The Revised Report distinguishes two types of special numeric objects: fixnums and flonums. Chez Scheme additionally distinguishes bignums (exact integers outside of the fixnum range) and ratnums (ratios of exact integers). It also provides a predicate for recognizing cflonums, which are flonums or inexact complex numbers.

```scheme
(bignum? obj) procedure
returns: #t if obj is a bignum, otherwise #f
libraries: (chezscheme)
```

$$
\begin{align*}
(bignum? \ 0) & \Rightarrow \ #f \\
(bignum? \ (\text{most-positive-fixnum})) & \Rightarrow \ #f \\
(bignum? \ (\text{most-negative-fixnum})) & \Rightarrow \ #f \\
(bignum? \ (* \ (\text{most-positive-fixnum}) \ 2)) & \Rightarrow \ #t \\
(bignum? \ 3/4) & \Rightarrow \ #f \\
(bignum? \ 'a) & \Rightarrow \ #f
\end{align*}
$$
8.2. Fixnum Operations

Fixnum-specific procedures normally check their inputs and outputs (where appropriate), but at optimization level 3 the compiler generates, in most cases, code that does not perform these checks.

### (ratnum? obj)

**procedure**

returns: #t if obj is a ratnum, otherwise #f

libraries: (chezscheme)

(ratnum? 0) ⇒ #f
(ratnum? (* (most-positive-fixnum) 2)) ⇒ #f
(ratnum? 3/4) ⇒ #t
(ratnum? -10/2) ⇒ #f
(ratnum? -11/2) ⇒ #t
(ratnum? 'a) ⇒ #f

### (cflonum? obj)

**procedure**

returns: #t if obj is an inexact complexnum or flonum, otherwise #f

libraries: (chezscheme)

(cflonum? 0) ⇒ #f
(cflonum? 0.0) ⇒ #t
(cflonum? 3+4i) ⇒ #f
(cflonum? 3.0+4i) ⇒ #t
(cflonum? +i) ⇒ #f
(cflonum? +1.0i) ⇒ #t

8.2. Fixnum Operations

Fixnum-specific procedures normally check their inputs and outputs (where appropriate), but at optimization level 3 the compiler generates, in most cases, code that does not perform these checks.

### (most-positive-fixnum)

**procedure**

returns: the most positive fixnum supported by the system

### (most-negative-fixnum)

**procedure**

returns: the most negative fixnum supported by the system

libraries: (chezscheme)

These procedures are identical to the Revised\(^6\) Report greatest-fixnum and least-fixnum procedures.

### (fx= fixnum\(_1\) fixnum\(_2\) ...)

**procedure**

returns: #t if the relation holds, #f otherwise

libraries: (chezscheme)

The predicate fx= returns #t if its arguments are equal. The predicate fx< returns #t if its
arguments are monotonically increasing, i.e., each argument is greater than the preceding ones, while \( fx> \) returns \( \#t \) if its arguments are monotonically decreasing. The predicate \( fx\leq \) returns \( \#t \) if its arguments are monotonically nondecreasing, i.e., each argument is not less than the preceding ones, while \( fx\geq \) returns \( \#t \) if its arguments are monotonically nonincreasing. When passed only one argument, each of these predicates returns \( \#t \).

These procedures are similar to the Revised\(^6\) Report procedures \( fx=\?, \ fx<\?, \ fx>\?, \ fx\leq=? \), and \( fx\geq=? \) except that the Revised\(^6\) Report procedures require two or more arguments, and their names have the “?” suffix.

\[
\begin{align*}
(fx= 0) & \Rightarrow \#t \\
(fx= 0 0) & \Rightarrow \#t \\
(fx< (\text{most-negative-fixnum}) 0 (\text{most-positive-fixnum})) & \Rightarrow \#t \\
(\text{let} ([x 3]) (fx\leq 0 x 9)) & \Rightarrow \#t \\
(fx\leq 0 3 3) & \Rightarrow \#t \\
(fx\geq 0 0 (\text{most-negative-fixnum})) & \Rightarrow \#t
\end{align*}
\]

\[
\begin{align*}
(fxnonpositive? \ fixnum) & \quad \text{procedure} \\
& \text{returns:} \ \#t \ \text{if} \ fixnum \ \text{is not greater than zero,} \ \#f \ \text{otherwise} \\
(fxnonnegative? \ fixnum) & \quad \text{procedure} \\
& \text{returns:} \ \#t \ \text{if} \ fixnum \ \text{is not less than zero,} \ \#f \ \text{otherwise} \\
& \text{libraries:} \ (\text{chezscheme})
\end{align*}
\]

\( \text{fxnonpositive?} \) is equivalent to \((\lambda (x) (fx\leq x 0))\), and \( \text{fxnonnegative?} \) is equivalent to \((\lambda (x) (fx\geq x 0))\).

\[
\begin{align*}
(fxnonpositive? 128) & \Rightarrow \#f \\
(fxnonpositive? 0) & \Rightarrow \#t \\
(fxnonpositive? -1) & \Rightarrow \#t \\
(fxnonnegative? -65) & \Rightarrow \#f \\
(fxnonnegative? 0) & \Rightarrow \#t \\
(fxnonnegative? 1) & \Rightarrow \#t
\end{align*}
\]

\[
\begin{align*}
(fx+ \ fixnum \ \ldots) & \quad \text{procedure} \\
& \text{returns: the sum of the arguments} \ fixnum \ \ldots \\
& \text{libraries:} \ (\text{chezscheme})
\end{align*}
\]

When called with no arguments, \( fx+ \) returns 0.

\[
\begin{align*}
(fx+) & \Rightarrow 0 \\
(fx+ 1 2) & \Rightarrow 3 \\
(fx+ 3 4 5) & \Rightarrow 12 \\
(\text{apply} \ fx+ '(1 2 3 4 5)) & \Rightarrow 15
\end{align*}
\]
**8.2. Fixnum Operations**

**(fx- fixnum1 fixnum2 ...) procedure**
*returns: a fixnum*
*libraries: (chezscheme)*

When called with one argument, **fx-** returns the negative of **fixnum1**. Thus, (fx- fixnum1) is an idiom for (fx- 0 fixnum1).

When called with two or more arguments, **fx-** returns the result of subtracting the sum of the numbers **fixnum2 ...** from **fixnum1**.

(fx- 3) ⇒ -3  
(fx- 4 3) ⇒ 1  
(fx- 4 3 2 1) ⇒ -2

**(fx* fixnum ...) procedure**
*returns: the product of the arguments **fixnum ...**
*libraries: (chezscheme)*

When called with no arguments, **fx* returns 1.

(fx*) ⇒ 1  
(fx* 1 2) ⇒ 2  
(fx* 3 -4 5) ⇒ -60  
(apply fx* '(1 -2 3 -4 5)) ⇒ 120

**(fx/ fixnum1 fixnum2 ...) procedure**
*returns: see explanation*
*libraries: (chezscheme)*

When called with one argument, **fx/** returns the reciprocal of **fixnum1**. That is, (fx/ fixnum1) is an idiom for (fx/ 1 fixnum1).

When called with two or more arguments, **fx/** returns the result of dividing **fixnum1** by the product of the remaining arguments **fixnum2 ...**.

(fx/ 1) ⇒ 1  
(fx/ -17) ⇒ 0  
(fx/ 8 -2) ⇒ -4  
(fx/ -9 2) ⇒ -4  
(fx/ 60 5 3 2) ⇒ 2
(fx+/wraparound fixnum ...) procedure
(fx-/wraparound fixnum ...) procedure
(fx*/wraparound fixnum ...) procedure
(fxsll/wraparound fixnum ...) procedure
returns: the arithmetic result, wrapping on overflow
libraries: (chezscheme)

These functions are like \texttt{fx+}, \texttt{fx-}, \texttt{fx*}, and \texttt{fxsll}, but when the result is too large to fit in a fixnum, as many high bits of the result as necessary are discarded to make the result representable as a fixnum.

(fx1+ fixnum) procedure
(fx1- fixnum) procedure
returns: \texttt{fixnum} plus 1 or \texttt{fixnum} minus 1
libraries: (chezscheme)

(define fxplus
  (lambda (x y)
    (if (fxzero? x)
        y
        (fxplus (fx1- x) (fx1+ y))))))

(fxplus 7 8) \Rightarrow 15

\texttt{fx1+} and \texttt{fx1-} can be defined as follows:

(define fx1+ (lambda (x) (fx+ x 1)))
(define fx1- (lambda (x) (fx- x 1)))

(fxquotient fixnum1 fixnum2 ...) procedure
returns: see explanation
libraries: (chezscheme)

\texttt{fxquotient} is identical to \texttt{fx/}. See the description of \texttt{fx/} above.

(fxremainder fixnum1 fixnum2) procedure
returns: the fixnum remainder of \texttt{fixnum1} divided by \texttt{fixnum2}
libraries: (chezscheme)

The result of \texttt{fxremainder} has the same sign as \texttt{fixnum1}.

(fxremainder 16 4) \Rightarrow 0
(fxremainder 5 2) \Rightarrow 1
(fxremainder -45 7) \Rightarrow -3
(fxremainder 10 -3) \Rightarrow 1
(fxremainder -17 -9) \Rightarrow -8
8.3. Flonum Operations

Inexact real numbers are normally represented by flonums. A flonum is a single 64-bit double-precision floating point number. This section describes operations on flonums, most of which accept flonum arguments and return flonum values. In most cases, the operations are inline-coded or coded as machine language subroutines at optimize-level 3 with no argument type checking; full type checking is performed at lower optimize levels. Flonum-specific procedure names begin with the prefix “fl” to set them apart from their generic counterparts.

Inexact real numbers may also be represented by inexact complexnums with imaginary parts equal to zero, which cannot be used as input to the flonum-specific operators. Such numbers are produced, however, only from operations involving complex numbers with nonzero imaginary parts, by explicit calls to fl-make-rectangular, make-rectangular, or make-polar, or by numeric input in either polar or rectangular format.

(flonum->fixnum flonum) procedure
returns: the fixnum representation of flonum, truncated
libraries: (chezscheme)

The truncated value of flonum must fall within the fixnum range. flonum->fixnum is a restricted version of exact, which converts any numeric representation to its exact equivalent.

(flonum->fixnum 0.0) ⇒ 0
(flonum->fixnum 3.9) ⇒ 3
(flonum->fixnum -2.2) ⇒ -2
Numeric Operations

(fl= flonum1 flonum2 ...) procedure
(fl< flonum1 flonum2 ...) procedure
(fl> flonum1 flonum2 ...) procedure
(fl<= flonum1 flonum2 ...) procedure
(fl>= flonum1 flonum2 ...) procedure

returns: #t if the relation holds, #f otherwise
libraries: (chezscheme)

The predicate fl= returns #t if its arguments are equal. The predicate fl< returns #t if its arguments are monotonically increasing, i.e., each argument is greater than the preceding ones, while fl> returns #t if its arguments are monotonically decreasing. The predicate fl<= returns #t if its arguments are monotonically nondecreasing, i.e., each argument is not less than the preceding ones, while fl>= returns #t if its arguments are monotonically nonincreasing. When passed only one argument, each of these predicates returns #t.

IEEE NANs are not comparable, i.e., comparisons involving NANs always return #f.

These procedures are similar to the Revised⁶ Report procedures fl=?, fl<?, fl?>, fl<=?, and fl>=? except that the Revised⁶ Report procedures require two or more arguments, and their names have the “?” suffix.

(flnonpositive? fl) procedure
returns: #t if fl is not greater than zero, #f otherwise
(flnonnegative? fl) procedure
returns: #t if fl is not less than zero, #f otherwise
libraries: (chezscheme)

flnonpositive? is equivalent to (lambda (x) (fl<= x 0.0)), and flnonnegative? is equivalent to (lambda (x) (fl>= x 0.0)).

Even if the flonum representation distinguishes -0.0 from +0.0, both are considered nonpositive and nonnegative.

(flnonpositive? -0.0) ⇒ #t
(flnonpositive? +0.0) ⇒ #f

8.3. Flonum Operations

(flnonnegative? -65.0) ⇒ #f
(flnonnegative? 0.0) ⇒ #t
(flnonnegative? -0.0) ⇒ #t
(flnonnegative? 1.0) ⇒ #t
(flnonnegative? +nan.0) ⇒ #f
(flnonpositive? +nan.0) ⇒ #f
(flnonnegative? +inf.0) ⇒ #t
(flnonnegative? -inf.0) ⇒ #f

(flsingle fl) procedure
returns: a possibly less precise variant of fl
libraries: (chezscheme)

Potentially discards precision from fl so that the result is representable as a 32-bit IEEE floating-point number.

(decode-float x) procedure
returns: see below
libraries: (chezscheme)

x must be a flonum. decode-float returns a vector with three integer elements, m, e, and s, such that \( x = sm2^e \). It is useful primarily in the printing of floating-point numbers.

(decode-float 1.0) ⇒ #(4503599627370496 -52 1)
(decode-float -1.0) ⇒ #(4503599627370496 -52 -1)

(define slow-identity
  (lambda (x)
    (inexact
      (let ([v (decode-float x)])
        (let ([m (vector-ref v 0)]
              [e (vector-ref v 1)]
              [s (vector-ref v 2)])
          (* s m (expt 2 e))))))

(slow-identity 1.0) ⇒ 1.0
(slow-identity -1e20) ⇒ -1e20

(fllp flonum) procedure
returns: see below
libraries: (chezscheme)

fllp returns the 12-bit integer consisting of the exponent plus highest order represented bit of a flonum (ieee 64-bit floating-point number). It can be used to compute a fast approximation of the logarithm of the number.
8. Numeric Operations

(fl 0.0) ⇒ 0
(fl 1.0) ⇒ 2046
(fl -1.0) ⇒ 2046

(fl 1.5) ⇒ 2047
(fl +inf.0) ⇒ 4094
(fl -inf.0) ⇒ 4094

(fl #b1.0e-1111111111) ⇒ 1
(fl #b1.0e-10000000000) ⇒ 0

8.4. Inexact Complex Operations

The procedures described in this section provide mechanisms for creating and operating on inexact complex numbers. Inexact complex numbers with nonzero imaginary parts are represented as inexact complexnums. An inexact complexnum contains two 64-bit double-precision floating point numbers. Inexact complex numbers with imaginary parts equal to zero (in other words, inexact real numbers) may be represented as either inexact complexnums or flonums. The operations described in this section accept any mix of inexact complexnum and flonum arguments (collectively, “cflonums”).

In most cases, the operations are performed with minimal type checking at optimize-level 3; full type checking is performed at lower optimize levels. Inexact complex procedure names begin with the prefix “cfl” to set them apart from their generic counterparts.

(fl-make-rectangular flonum1 flonum2)
procedure
returns: an inexact complexnum
libraries: (chezscheme)

The inexact complexnum produced by fl-make-rectangular has real part equal to flonum1 and imaginary part equal to flonum2.

(fl-make-rectangular 2.0 -3.0) ⇒ 2.0-3.0i
(fl-make-rectangular 2.0 0.0) ⇒ 2.0+0.0i
(fl-make-rectangular 2.0 -0.0) ⇒ 2.0-0.0i

(cfl-real-part cflonum)
procedure
returns: the real part of cflonum
(cfl-imag-part cflonum)
procedure
returns: the imaginary part of cflonum
libraries: (chezscheme)

(cfl-real-part 2.0-3.0i) ⇒ 2.0
(cfl-imag-part 2.0-3.0i) ⇒ -3.0
(cfl-imag-part 2.0-0.0i) ⇒ -0.0
(cfl-imag-part 2.0-inf.0i) ⇒ -inf.0
8.4. Inexact Complex Operations

(cfl= cflonum ...) procedure
returns: #t if its arguments are equal, #f otherwise
libraries: (chezscheme)

(cfl= 7.0+0.0i 7.0) ⇒ #t
(cfl= 1.0+2.0i 1.0+2.0i) ⇒ #t
(cfl= 1.0+2.0i 1.0-2.0i) ⇒ #f

(cfl+ cflonum ...) procedure
(cfl* cflonum ...)
(cfl- cflonum_1 cflonum_2 ...)
(cfl/ cflonum_1 cflonum_2 ...)
returns: a cflonum
libraries: (chezscheme)

These procedures compute the sum, difference, product, or quotient of inexact complex quantities, whether these quantities are represented by flonums or inexact complexnums. For example, if cfl+ receives two flonum arguments a and b, it returns the sum a + b; in this case, it behaves the same as fl+. With two inexact complexnum arguments a + bi and c + di, it returns the sum (a + c) + (b + d)i. If one argument is a flonum a and the other an inexact complexnum c + di, cfl+ returns (a + c) + di.

When passed zero arguments, cfl+ returns 0.0 and cfl* returns 1.0. When passed one argument, cfl- returns the additive inverse of the argument, and cfl/ returns the multiplicative inverse of the argument. When passed three or more arguments, cfl- returns the difference between its first and the sum of its remaining arguments, and cfl/ returns the quotient of its first and the product of its remaining arguments.

(cfl+) ⇒ 0.0
(cfl*) ⇒ 1.0
(cfl- 5.0+1.0i) ⇒ -5.0-1.0i
(cfl/ 2.0+2.0i) ⇒ 0.25-0.25i

(cfl+ 1.0+2.2i -3.7+5.3i) ⇒ -2.7+7.5i
(cfl+ 1.0 -5.3) ⇒ -4.3
(cfl+ 1.0 2.0 -5.3i) ⇒ 3.0-5.3i
(cfl- 1.0+2.5i -3.7) ⇒ 4.7+2.5i
(cfl* 1.0+2.0i 3.0+4.0i) ⇒ -5.0+10.0i
(cfl/ -5.0+10.0i 1.0+2.0i 2.0) ⇒ 1.5+2.0i

(cfl-conjugate cflonum) procedure
returns: complex conjugate of cflonum
libraries: (chezscheme)

The procedure cfl-conjugate, when passed an inexact complex argument a + bi, returns its complex conjugate a + (-b)i.

See also conjugate, which is a generic version of this operator that returns the complex conjugate of any valid representation for a complex number.
(cfl-conjugate 3.0) ⇒ 3.0
(cfl-conjugate 3.0+4.0i) ⇒ 3.0-4.0i
(cfl-conjugate 1e-20-2e-30i) ⇒ 1e-20+2e-30i

(cfl-magnitude-squared cflonum) procedure
returns: magnitude of cflonum squared
libraries: (chezscheme)

The procedure cfl-magnitude-squared, when passed an inexact complex argument \( a + bi \) returns a flonum representing the magnitude of the argument squared, i.e., \( a^2 + b^2 \).

See also magnitude-squared, which is a generic version of this operator that returns the magnitude squared of any valid representation for a complex number. Both operations are similar to the magnitude procedure, which returns the magnitude, \( \sqrt{a^2 + b^2} \), of its generic complex argument.

(cfl-magnitude-squared 3.0) ⇒ 9.0
(cfl-magnitude-squared 3.0-4.0i) ⇒ 25.0

8.5. Bitwise and Logical Operators

Chez Scheme provides a set of logical operators that allow exact integers (fixnums and bignums) to be treated as sets or sequences of bits. These operators include logand (bitwise logical and), logior (bitwise logical or), logxor (bitwise logical exclusive or), lognot (bitwise logical not), logtest (test multiple bits), logbit? (test single bit), logbit0 (reset single bit), logbit1 (set single bit), and ash (arithmetic shift). Each of these operators treats its arguments as two’s complement integers, regardless of the underlying representation. This treatment can be exploited to represent infinite sets: a negative number represents an infinite number of one bits beyond the leftmost zero, and a nonnegative number represents an infinite number of zero bits beyond the leftmost one bit.

Fixnum equivalents of the logical operators are provided, as fxlogand, fxlogior, fxlogxor, fxlognot, fxlogtest, fxlogbit?, fxlogbit0, and fxlogbit1. Three separate fixnum operators are provided for shifting: fxsll (shift-left logical), fxsr1 (shift-right logical), fxsr (shift-right arithmetic). Logical and arithmetic shifts differ only for right shifts. Shift-right logical shifts in zero bits on the left end, and shift-right arithmetic replicates the sign bit. Logical shifts do not make sense for arbitrary-precision integers, since these have no “left end” into which bits must be shifted.

(logand int ...) procedure
returns: the logical “and” of the arguments int ...
libraries: (chezscheme)

The arguments must be exact integers (fixnums or bignums) and are treated as two’s complement integers, regardless of the underlying representation. With no arguments, logand returns -1, i.e., all bits set.
8.5. Bitwise and Logical Operators

(logand) ⇒ -1
(logand 15) ⇒ 15
(logand -1 -1) ⇒ -1
(logand -1 0) ⇒ 0
(logand 5 3) ⇒ 1
(logand #x173C8D95 7) ⇒ 5
(logand #x173C8D95 -8) ⇒ #x173C8D90
(logand #b1100 #b1111 #b1101) ⇒ #b1100

(logior int ...) procedure
(logor int ...) procedure

returns: the logical “or” of the arguments int ...
libraries: (chezscheme)

The arguments must be exact integers (fixnums or bignums) and are treated as two’s complement integers, regardless of the underlying representation. With no arguments, logior returns 0, i.e., all bits reset.

(logior) ⇒ 0
(logior 15) ⇒ 15
(logior -1 -1) ⇒ -1
(logior -1 0) ⇒ -1
(logior 5 3) ⇒ 7
(logior #b111000 #b101010) ⇒ #b111010
(logior #b1000 #b0100 #b0010) ⇒ #b1110
(apply logior '(1 2 4 8 16)) ⇒ 31

(logxor int ...) procedure

returns: the logical “exclusive or” of the arguments int ...
libraries: (chezscheme)

The arguments must be exact integers (fixnums or bignums) and are treated as two’s complement integers, regardless of the underlying representation. With no arguments, logxor returns 0, i.e., all bits reset.

(logxor) ⇒ 0
(logxor 15) ⇒ 15
(logxor -1 -1) ⇒ 0
(logxor -1 0) ⇒ -1
(logxor 5 3) ⇒ 6
(logxor #b111000 #b101010) ⇒ #b010010
(logxor #b1100 #b0100 #b0110) ⇒ #b1110
8. Numeric Operations

<table>
<thead>
<tr>
<th>(lognot int)</th>
<th>procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>returns:</td>
<td>the logical “not” of int</td>
</tr>
<tr>
<td>libraries:</td>
<td>(chezscheme)</td>
</tr>
</tbody>
</table>

The argument must be an exact integer (fixnum or bignum) and is treated as a two’s complement integer, regardless of the underlying representation.

(lognot -1) ⇒ 0  
(lognot 0) ⇒ -1  
(lognot 7) ⇒ -8  
(lognot -8) ⇒ 7

<table>
<thead>
<tr>
<th>(logbit? index int)</th>
<th>procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>returns:</td>
<td>#t if the specified bit is set, otherwise #f</td>
</tr>
<tr>
<td>libraries:</td>
<td>(chezscheme)</td>
</tr>
</tbody>
</table>

index must be a nonnegative exact integer. int must be an exact integer (fixnum or bignum) and is treated as a two’s complement integer, regardless of the underlying representation.

logbit? returns #t if the bit at index index of int is set (one) and #f otherwise. The index is zero-based, counting from the lowest-order toward higher-order bits. There is no upper limit on the index; for nonnegative values of int, the bits above the highest order set bit are all considered to be zero, and for negative values, the bits above the highest order reset bit are all considered to be one.

logbit? is equivalent to

(lambada (k n) (not (zero? (logand n (ash 1 k))))))

but more efficient.

(logbit? 0 #b1110) ⇒ #f  
(logbit? 1 #b1110) ⇒ #t  
(logbit? 2 #b1110) ⇒ #t  
(logbit? 3 #b1110) ⇒ #t  
(logbit? 4 #b1110) ⇒ #f  
(logbit? 100 #b1110) ⇒ #f

(logbit? 0 -6) ⇒ #f ; the two’s complement of -6 is 1...1010  
(logbit? 1 -6) ⇒ #t  
(logbit? 2 -6) ⇒ #f  
(logbit? 3 -6) ⇒ #t  
(logbit? 100 -6) ⇒ #t

(logbit? (random 1000000) 0) ⇒ #f  
(logbit? (random 1000000) -1) ⇒ #t  
(logbit? 20000 (ash 1 20000)) ⇒ #t
8.5. Bitwise and Logical Operators

(logtest int₁ int₂) procedure

returns: #t if any common bits are set, otherwise #f
libraries: (chezscheme)

The arguments must be exact integers (fixnums or bignums) and are treated as two’s complement integers, regardless of the underlying representation.

logtest returns #t if any bit set in one argument is also set in the other. It returns #f if the two arguments have no set bits in common.

logtest is equivalent to

(lambda (n₁ n₂) (not (zero? (logand n₁ n₂))))

but more efficient.

(logtest #b10001 #b1110) ⇒ #f
(logtest #b10101 #b1110) ⇒ #t
(logtest #b111000 #b110111) ⇒ #t

(logtest #b101 -6) ⇒ #f ; the two’s complement of -6 is 1...1010
(logtest #b1000 -6) ⇒ #t
(logtest 100 -6) ⇒ #t

(logtest (+ (random 1000000) 1) 0) ⇒ #f
(logtest (+ (random 1000000) 1) -1) ⇒ #t

(logtest (ash #b101 20000) (ash #b111 20000)) ⇒ #t

(logbit0 index int) procedure

returns: the result of clearing bit index of int
libraries: (chezscheme)

index must be a nonnegative exact integer. int must be an exact integer (fixnum or bignum) and is treated as a two’s complement integer, regardless of the underlying representation.

The index is zero-based, counting from the lowest-order toward higher-order bits. As with logbit?, there is no upper limit on the index.

logbit0 is equivalent to

(lambda (i n) (logand (lognot (ash 1 i)) n))

but more efficient.

(logbit0 3 #b10101010) ⇒ #b10100010
(logbit0 4 #b10101010) ⇒ #b10101010
(logbit0 0 -1) ⇒ -2
**(logbit1 index int)**  
oprocedure  
returns: the result of setting bit index of int  
libraries: (chezscheme)

index must be a nonnegative exact integer. int must be an exact integer (fixnum or bignum) and is treated as a two’s complement integer, regardless of the underlying representation. The index is zero-based, counting from the lowest-order toward higher-order bits. As with logbit?, there is no upper limit on the index.

logbit1 is equivalent to

(lamda (i n) (logor (ash 1 i) n))

but more efficient.

(logbit1 3 #b10101010) => #b10101010  
(logbit1 4 #b10101010) => #b10111010  
(logbit1 4 0) => #b10000  
(logbit1 0 -2) => -1

**(ash int count)**  
oprocedure  
returns: int shifted left arithmetically by count.  
libraries: (chezscheme)

Both arguments must be exact integers. The first argument is treated as a two’s complement integer, regardless of the underlying representation. If count is negative, int is shifted right by −count bits.

(ash 8 0) => 8  
(ash 8 2) => 32  
(ash 8 -2) => 2  
(ash -1 2) => -4  
(ash -1 -2) => -1

**(fxlogand fixnum ...)**  
oprocedure  
returns: the logical “and” of the arguments fixnum ...  
libraries: (chezscheme)

The arguments are treated as two’s complement integers, regardless of the underlying representation. With no arguments, fxlogand returns -1, i.e., all bits set.

(fxlogand) => -1  
(fxlogand 15) => 15  
(fxlogand -1 -1) => -1  
(fxlogand -1 0) => 0  
(fxlogand 5 3) => 1  
(fxlogand #b11000 #b101010) => #b101000  
(fxlogand #b1100 #b1111 #b1101) => #b1100
8.5. Bitwise and Logical Operators

**fxlogior fixnum ...**

*procedure*

returns: the logical “or” of the arguments *fixnum* ...

libraries: *(chezscheme)*

The arguments are treated as two’s complement integers, regardless of the underlying representation. With no arguments, *fxlogior* returns 0, i.e., all bits reset.

```scheme
(fxlogior) ⇒ 0
(fxlogior 15) ⇒ 15
(fxlogior -1 -1) ⇒ -1
(fxlogior -1 0) ⇒ -1
(fxlogior #b111000 #b101010) ⇒ #b111010
(fxlogior #b1000 #b0100 #b0010) ⇒ #b1110
(apply fxlogior '(1 2 4 8 16)) ⇒ 31
```

**fxlogxor fixnum ...**

*procedure*

returns: the logical “exclusive or” of the arguments *fixnum* ...

libraries: *(chezscheme)*

The arguments are treated as two’s complement integers, regardless of the underlying representation. With no arguments, *fxlogxor* returns 0, i.e., all bits reset.

```scheme
(fxlogxor) ⇒ 0
(fxlogxor 15) ⇒ 15
(fxlogxor -1 -1) ⇒ 0
(fxlogxor -1 0) ⇒ -1
(fxlogxor 5 3) ⇒ 6
(fxlogxor #b111000 #b101010) ⇒ #b010010
(fxlogxor #b1100 #b0100 #b0110) ⇒ #b1110
```

**fxlognot fixnum**

*procedure*

returns: the logical “not” of *fixnum*

libraries: *(chezscheme)*

The argument is treated as a two’s complement integer, regardless of the underlying representation.

```scheme
(fxlognot -1) ⇒ 0
(fxlognot 0) ⇒ -1
(fxlognot 1) ⇒ -2
(fxlognot -2) ⇒ 1
```
(fxlogbit? index fixnum)

procedure
returns: #t if the specified bit is set, otherwise #f
libraries: (chezscheme)

index must be a nonnegative fixnum. fixnum is treated as a two’s complement integer, regardless of the underlying representation.

fxlogbit? returns #t if the bit at index index of fixnum is set (one) and #f otherwise. The index is zero-based, counting from the lowest-order toward higher-order bits. The index is limited only by the fixnum range; for nonnegative values of fixnum, the bits above the highest order set bit are all considered to be zero, and for negative values, the bits above the highest order reset bit are all considered to be one.

(fxlogbit? 0 #b1110) ⇒ #f
(fxlogbit? 1 #b1110) ⇒ #t
(fxlogbit? 2 #b1110) ⇒ #t
(fxlogbit? 3 #b1110) ⇒ #t
(fxlogbit? 4 #b1110) ⇒ #f
(fxlogbit? 100 #b1110) ⇒ #f
(fxlogbit? 0 -6) ⇒ #f ; the two's complement of -6 is 1...1010
(fxlogbit? 1 -6) ⇒ #t
(fxlogbit? 2 -6) ⇒ #f
(fxlogbit? 3 -6) ⇒ #t
(fxlogbit? 100 -6) ⇒ #t
(fxlogbit? (random 1000000) 0) ⇒ #f
(fxlogbit? (random 1000000) -1) ⇒ #t

(fxlogtest fixnum1 fixnum2)

procedure
returns: #t if any common bits are set, otherwise #f
libraries: (chezscheme)

The arguments are treated as two’s complement integers, regardless of the underlying representation.

fxlogtest returns #t if any bit set in one argument is also set in the other. It returns #f if the two arguments have no set bits in common.

(fxlogtest #b10001 #b1110) ⇒ #f
(fxlogtest #b10101 #b1110) ⇒ #t
(fxlogtest #b111000 #b110111) ⇒ #t
(fxlogtest #b101 -6) ⇒ #f ; the two's complement of -6 is 1...1010
(fxlogtest #b1000 -6) ⇒ #t
(fxlogtest 100 -6) ⇒ #t
(fxlogtest (+ (random 1000000) 1) 0) ⇒ #f
(fxlogtest (+ (random 1000000) 1) -1) ⇒ #t
8.5. Bitwise and Logical Operators

\( (fxlogbit0 \ index \ fixnum) \)

Procedure
returns: the result of clearing bit \( index \) of \( fixnum \)
libraries: (chezscheme)

\( fixnum \) is treated as a two's complement integer, regardless of the underlying representation. \( index \) must be nonnegative and less than the number of bits in a \( fixnum \), excluding the sign bit, i.e., less than \( \text{integer-length}(\text{most-positive-fixnum}) \). The index is zero-based, counting from the lowest-order toward higher-order bits.

\( fxlogbit0 \) is equivalent to

\( \lambda (i \ n) (fxlogand (fxlognot (fxsll 1 i)) n) \)

but more efficient.

\( (fxlogbit0 \ 3 \ #b10101010) \Rightarrow \ #b10100010 \)
\( (fxlogbit0 \ 4 \ #b10101010) \Rightarrow \ #b10101010 \)
\( (fxlogbit0 \ 0 \ -1) \Rightarrow \ -2 \)

\( (fxlogbit1 \ index \ fixnum) \)

Procedure
returns: the result of setting bit \( index \) of \( fixnum \)
libraries: (chezscheme)

\( fixnum \) is treated as a two’s complement integer, regardless of the underlying representation. \( index \) must be nonnegative and less than the number of bits in a \( fixnum \), excluding the sign bit, i.e., less than \( \text{integer-length}(\text{most-positive-fixnum}) \). The index is zero-based, counting from the lowest-order toward higher-order bits.

\( fxlogbit1 \) is equivalent to

\( \lambda (i \ n) (fxlogor (fxsll 1 i) n) \)

but more efficient.

\( (fxlogbit1 \ 3 \ #b10101010) \Rightarrow \ #b10101010 \)
\( (fxlogbit1 \ 4 \ #b10101010) \Rightarrow \ #b10111010 \)
\( (fxlogbit1 \ 4 \ 0) \Rightarrow \ #b10000 \)
\( (fxlogbit1 \ 0 \ -2) \Rightarrow \ -1 \)

\( (fxsll \ fixnum \ count) \)

Procedure
returns: \( fixnum \) shifted left by \( count \)
libraries: (chezscheme)

\( fixnum \) is treated as a two’s complement integer, regardless of the underlying representation. \( count \) must be nonnegative and not more than the number of bits in a \( fixnum \), i.e., \( (+ \text{integer-length}(\text{most-positive-fixnum}) \ 1) \). An exception is raised with condition-type \&implementation-restriction if the result cannot be represented as a \( fixnum \).
(fxsll 1 2) ⇒ 4
(fxsll -1 2) ⇒ -4

(fxsrl fixnum count) procedure
returns: fixnum logically shifted right by count
libraries: (chezscheme)

fixnum is treated as a two’s complement integer, regardless of the underlying representation. count must be nonnegative and not more than the number of bits in a fixnum, i.e., (+ (integer-length (most-positive-fixnum)) 1).

(fxsrl 4 2) ⇒ 1
(= (fxsrl -1 1) (most-positive-fixnum)) ⇒ #t

(fxsra fixnum count) procedure
returns: fixnum arithmetically shifted right by count
libraries: (chezscheme)

fixnum is treated as a two’s complement integer, regardless of the underlying representation. count must be nonnegative and not more than the number of bits in a fixnum, i.e., (+ (integer-length (most-positive-fixnum)) 1).

(fxsra 64 3) ⇒ 8
(fxsra -1 1) ⇒ -1
(fxsra -64 3) ⇒ -8

(fxpopcount fixnum) procedure
(fxpopcount32 fixnum) procedure
(fxpopcount16 fixnum) procedure
returns: number of bits set in fixnum
libraries: (chezscheme)

fixnum must be non-negative, and it must have a width of no more than 32 for fxpopcount32 or no more than 16 for fxpopcount16. fixnum is treated as a two’s complement integer, regardless of the underlying representation.

See also fxbits-count, which produces the same result as fxpopcount for the domain of fxpopcount. Because fxbits-count also handles negative arguments, however, it does not map as simply to certain processor instructions.
8.6. Random Number Generation

(random real) procedure
returns: a nonnegative pseudo-random number less than real
libraries: (chezscheme)

real must be a positive integer or positive inexact real number.

(random 1) ⇒ 0
(random 1029384535235) ⇒ 1029384535001, every now and then
(random 1.0) ⇒ 0.5, every now and then

(random-seed) thread parameter
libraries: (chezscheme)

The random number generator allows the current random seed to be obtained and modified via the parameter random-seed.

When called without arguments, random-seed returns the current random seed. When called with one argument, which must be a nonnegative exact integer ranging from 1 through $2^{32} - 1$, random-seed sets the current random seed to the argument.

(let ([s (random-seed)])
  (let ([r1 (random 1.0)])
    (random-seed s)
    (eqv? (random 1.0) r1))) ⇒ #t

(make-pseudo-random-generator) procedure
returns: a fresh pseudo-random generator
libraries: (chezscheme)

Creates a pseudo-random generator state for use with pseudo-random-generator-next!. This generator uses a more modern algorithm than random and generates number sequences that better approximate true randomness.

The initial state of the pseudo-random generator is based on the current time, which is good enough for generating variability in most programs but not good enough for security purposes.

(pseudo-random-generator? val) procedure
returns: a boolean
libraries: (chezscheme)

Checks whether val is a pseudo-random generator state.
8. Numeric Operations

(pseudo-random-generator-next! prgen)  
returns: a pseudo-random number  
libraries: (chezscheme)

prgen must be a pseudo-random generator state. If below-int is provided, it must be a positive, exact integer.

Steps a pseudo-random generator to produce a number. The result is an inexact number between 0.0 (inclusive) and 1.0 (exclusive) if below-int is not provided. If below-int is provided, the result is an exact integer between 0 (inclusive) and below-int (exclusive).

(pseudo-random-generator-seed! prgen seed-int)  
returns: unspecified  
libraries: (chezscheme)

prgen must be a pseudo-random generator state, and seed-int must be a nonnegative, exact integer.

Sets the state of a pseudo-random generator using only 31 or so bits of seed-int. This procedure is useful for initializing the state of a pseudo-random generator to one of a small number of known states for triggering predictable output, but it is not a good way to put a generator into an unpredictable state.

(pseudo-random-generator->vector prgen)  
returns: a vector  
libraries: (chezscheme)

(vector->pseudo-random-generator vec)  
(vector->pseudo-random-generator! prgen vec)  
returns: unspecified  
libraries: (chezscheme)

prgen must be a pseudo-random generator state, and vec must be a vector previously produced by pseudo-random-generator->vector.

pseudo-random-generator->vector converts the current state of a pseudo-random generator to a vector of numbers, vector->pseudo-random-generator creates a fresh pseudo-random generator with the same state, and vector->pseudo-random-generator! changes an existing pseudo-random generator to have the same state.
8.7. Miscellaneous Numeric Operations

\[ (= \text{num}_1 \text{num}_2 \text{num}_3 \ldots) \quad \text{procedure} \]
\[ (< \text{real}_1 \text{real}_2 \text{real}_3 \ldots) \quad \text{procedure} \]
\[ (> \text{real}_1 \text{real}_2 \text{real}_3 \ldots) \quad \text{procedure} \]
\[ (\leq \text{real}_1 \text{real}_2 \text{real}_3 \ldots) \quad \text{procedure} \]
\[ (\geq \text{real}_1 \text{real}_2 \text{real}_3 \ldots) \quad \text{procedure} \]

returns: \#t if the relation holds, \#f otherwise

libraries: (chezscheme)

These predicates are identical to the Revised\textsuperscript{6} Report counterparts, except they are extended to accept one or more rather than two or more arguments. When passed one argument, each of these predicates returns \#t.

\[ (> 3/4) \Rightarrow \#t \]
\[ (< 3/4) \Rightarrow \#t \]
\[ (= 3/4) \Rightarrow \#t \]

\[ (1+ \text{num}) \quad \text{procedure} \]
\[ (\text{add1} \text{num}) \quad \text{procedure} \]
\[ (1- \text{num}) \quad \text{procedure} \]
\[ (-1+ \text{num}) \quad \text{procedure} \]
\[ (\text{sub1} \text{num}) \quad \text{procedure} \]

returns: \text{num} plus 1 or \text{num} minus 1

libraries: (chezscheme)

1+ and \text{add1} are equivalent to (\text{lambda} (x) (+ x 1)); 1-, \text{-1+}, and \text{sub1} are equivalent to (\text{lambda} (x) (- x 1)).

(define plus
  ; x should be a nonnegative integer
  (lambda (x y)
    (if (zero? x)
        y
        (plus (1- x) (1+ y))))))

(plus 7 8) \Rightarrow 15

(define double
  ; x should be a nonnegative integer
  (lambda (x)
    (if (zero? x)
        0
        (add1 (add1 (double (sub1 x)))))))

(double 7) \Rightarrow 14
(expt-mod int1 int2 int3) procedure
returns: int1 raised to the int2 power, modulo int3
libraries: (chezscheme)

int1, int2 and int3 must be nonnegative integers. expt-mod performs its computation in such a way that the intermediate results are never much larger than int3. This means that when int2 is large, expt-mod is more efficient than the equivalent procedure (lambda (x y z) (modulo (expt x y) z)).

(expt-mod 2 4 3) ⇒ 1
(expt-mod 2 76543 76543) ⇒ 2

(isqrt n) procedure
returns: the integer square root of n
libraries: (chezscheme)

n must be a nonnegative integer. The integer square root of n is defined to be \[ \lfloor \sqrt{n} \rfloor. \]

(isqrt 0) ⇒ 0
(isqrt 16) ⇒ 4
(isqrt 16.0) ⇒ 4.0
(isqrt 20) ⇒ 4
(isqrt 20.0) ⇒ 4.0
(isqrt (* 2 (expt 10 20))) ⇒ 14142135623

(integer-length n) procedure
returns: see below
libraries: (chezscheme)

The procedure integer-length returns the length in bits of the smallest two’s complement representation for n, with an assumed leading 1 (sign) bit for negative numbers. For zero, integer-length returns 0.

(integer-length 0) ⇒ 0
(integer-length 1) ⇒ 1
(integer-length 2) ⇒ 2
(integer-length 3) ⇒ 2
(integer-length 4) ⇒ 3
(integer-length #b10000000) ⇒ 8
(integer-length #b11111111) ⇒ 8
(integer-length -1) ⇒ 0
(integer-length -2) ⇒ 1
(integer-length -3) ⇒ 2
(integer-length -4) ⇒ 2
8.7. Miscellaneous Numeric Operations

(nonpositive? real) procedure
returns: #t if real is not greater than zero, #f otherwise
libraries: (chezscheme)

nonpositive? is equivalent to (lambda (x) (<= x 0)).

(nonpositive? 128) ⇒ #f
(nonpositive? 0.0) ⇒ #t
(nonpositive? 1.8e-15) ⇒ #f
(nonpositive? -2/3) ⇒ #t

(nonnegative? real) procedure
returns: #t if real is not less than zero, #f otherwise
libraries: (chezscheme)

nonnegative? is equivalent to (lambda (x) (>= x 0)).

(nonnegative? -65) ⇒ #f
(nonnegative? 0) ⇒ #t
(nonnegative? -0.0121) ⇒ #f
(nonnegative? 15/16) ⇒ #t

(conjugate num) procedure
returns: complex conjugate of num
libraries: (chezscheme)

The procedure conjugate, when passed a complex argument \( a + bi \), returns its complex conjugate \( a + (-b)i \).

(conjugate 3.0+4.0i) ⇒ 3.0-4.0i
(conjugate 1e-20-2e-30i) ⇒ 1e-20+2e-30i
(conjugate 3) ⇒ 3

(magnitude-squared num) procedure
returns: magnitude of num squared
libraries: (chezscheme)

The procedure magnitude-squared, when passed a complex argument \( a + bi \) returns its magnitude squared, i.e., \( a^2 + b^2 \).

(magnitude-squared 3.0-4.0i) ⇒ 25.0
(magnitude-squared 3.0) ⇒ 9.0
(sinh num) procedure
(cosh num) procedure
(tanh num) procedure
returns: the hyperbolic sine, cosine, or tangent of num
libraries: (chezscheme)

(sinh 0.0) ⇒ 0.0
(cosh 0.0) ⇒ 1.0
(tanh -0.0) ⇒ -0.0

(asinh num) procedure
(acosh num) procedure
(atanh num) procedure
returns: the hyperbolic arc sine, arc cosine, or arc tangent of num
libraries: (chezscheme)

(acosh 0.0) ⇒ 0.0+1.5707963267948966i
(acosh 1.0) ⇒ 0.0
(atanh -1.0) ⇒ -inf.0

(string->number string) procedure
(string->number string radix) procedure
returns: the number represented by string, or #f
libraries: (chezscheme)

This procedure is identical to the Revised\(^6\) Report version except that radix may be any exact integer between 2 and 36, inclusive. The Revised\(^6\) Report version requires radix to be in the set \{2, 8, 10, 16\}.

(string->number "211012" 3) ⇒ 559
(string->number "tobeornottobe" 36) ⇒ 140613689159812836698

(number->string num) procedure
(number->string num radix) procedure
(number->string num radix precision) procedure
returns: an external representation of num as a string
libraries: (chezscheme)

This procedure is identical to the Revised\(^6\) Report version except that radix may be any exact integer between 2 and 36, inclusive. The Revised\(^6\) Report version requires radix to be in the set \{2, 8, 10, 16\}.

(number->string 10000 4) ⇒ "2130100"
(number->string 10000 27) ⇒ "DJA"
This chapter describes Chez Scheme’s generic port facility, operations on ports, and various Chez Scheme extensions to the standard set of input/output operations. See Chapter 7 of The Scheme Programming Language, 4th Edition or the Revised6 Report on Scheme for a description of standard input/output operations. Definitions of a few sample generic ports are given in Section 9.17.

Chez Scheme closes file ports automatically after they become inaccessible to the program or when the Scheme program exits, but it is best to close ports explicitly whenever possible.

9.1. Generic Ports

Chez Scheme’s “generic port” facility allows the programmer to add new types of textual ports with arbitrary input/output semantics. It may be used, for example, to define any of the built-in Common Lisp [30] stream types, i.e., synonym streams, broadcast streams, concatenated streams, two-way streams, echo streams, and string streams. It may also be used to define more exotic ports, such as ports that represent windows on a bit-mapped display or ports that represent processes connected to the current process via pipes or sockets.

Each port has an associated port handler. A port handler is a procedure that accepts messages in an object-oriented style. Each message corresponds to one of the low-level Scheme operations on ports, such as read-char and close-input-port (but not read, which is defined in terms of the lower-level operations). Most of these operations simply call the handler immediately with the corresponding message.

Standard messages adhere to the following conventions: the message name is the first argument to the handler. It is always a symbol, and it is always the name of a primitive Scheme operation on ports. The additional arguments are the same as the arguments to the primitive procedure and occur in the same order. (The port argument to some of the primitive procedures is optional; in the case of the messages passed to a handler, the port argument is always supplied.) The following messages are defined for built-in ports:

- block-read port string count
- block-write port string count
- char-ready? port
- clear-input-port port
- clear-output-port port
Additional messages may be accepted by user-defined ports.

Chez Scheme input and output is normally buffered for efficiency. To support buffering, each input port contains an input buffer and each output port contains an output buffer. Bidirectional ports, ports that are both input ports and output ports, contain both input and output buffers. Input is not buffered if the input buffer is the empty string, and output is not buffered if the output buffer is the empty string. In the case of unbuffered input and output, calls to `read-char`, `write-char`, and similar messages cause the handler to be invoked immediately with the corresponding message. For buffered input and output, calls to these procedures cause the buffer to be updated, and the handler is not called under normal circumstances until the buffer becomes empty (for input) or full (for output). Handlers for buffered ports must not count on the buffer being empty or full when `read-char`, `write-char`, and similar messages are received, however, due to the possibility that (a) the handler is invoked through some other mechanism, or (b) the call to the handler is interrupted.

In the presence of keyboard, timer, and other interrupts, it is possible for a call to a port handler to be interrupted or for the handler itself to be interrupted. If the port is accessible outside of the interrupted code, there is a possibility that the interrupt handler will cause input or output to be performed on the port. This is one reason, as stated above, that port handlers must not count on the input buffer being empty or output buffer being full when a `read-char`, `write-char`, or similar message is received. In addition, port handlers may need to manipulate the buffers only with interrupts disabled (using `with-interrupts-disabled`).

Generic ports are created via one of the port construction procedures `make-input-port`, `make-output-port`, and `make-input/output-port` defined later in this chapter. Ports have seven accessible fields:

- `handler`, accessed with `port-handler`;
- `output-buffer`, accessed with `port-output-buffer`;
- `output-size`, accessed with `port-output-size`;
- `output-index`, accessed with `port-output-index`;
- `input-buffer`, accessed with `port-input-buffer`;
- `input-size`, accessed with `port-input-size`, and
- `input-index`, accessed with `port-input-index`.

The output-size and output-index fields are valid only for output ports, and the input-size
and input-index fields are valid only for input ports. The output and input size and index fields may be updated as well using the corresponding “set-field!” procedure.

A port’s output size determines how much of the port’s output buffer is actually available for writing by write-char. The output size is often the same as the string length of the port’s output buffer, but it can be set to less (but no less than zero) at the discretion of the programmer. The output index determines to which position in the port’s buffer the next character will be written. The output index should be between 0 and the output size, inclusive. If no output has occurred since the buffer was last flushed, the output index should be 0. If the index is less than the size, write-char stores its character argument into the specified character position within the buffer and increments the index. If the index is equal to the size, write-char leaves the fields of the port unchanged and invokes the handler.

A port’s input size determines how much of the port’s input buffer is actually available for reading by read-char. A port’s input size and input index are constrained in the same manner as output size and index, i.e., the input size must be between 0 and the string length of the input buffer (inclusive), and the input index must be between 0 and the input size (inclusive). Often, the input size is less than the length of the input buffer because there are fewer characters available to read than would fit in the buffer. The input index determines from which position in the input buffer the next character will be read. If the index is less than the size, read-char extracts the character in this position, increments the index, and returns the character. If the index is equal to the size, read-char leaves the fields of the port unchanged and invokes the handler.

The operation of peek-char is similar to that of read-char, except that it does not increment the input index. unread-char decrements the input index if it is greater than 0, otherwise it invokes the handler. char-ready? returns #t if the input index is less than the input size, otherwise it invokes the handler.

Although the fields shown and discussed above are logically present in a port, actual implementation details may differ. The current Chez Scheme implementation uses a different representation that allows read-char, write-char, and similar operations to be open-coded with minimal overhead. The access and assignment operators perform the conversion between the actual representation and the one shown above.

Port handlers receiving a message must return a value appropriate for the corresponding operation. For example, a handler receiving a read-char message must return a character or eof object (if it returns). For operations that return unspecified values, such as close-port, the handler is not required to return any particular value.

9.2. File Options

The Revised Report requires that the universe of a file-options enumeration set must include no-create, no-fail, and no-truncate, whose meanings are described within the description of the file-options syntax in Section 7.2 of The Scheme Programming Language, 4th Edition. Chez Scheme defines a number of additional file options:
compressed: An output file should be compressed when written; and a compressed input file should be decompressed when read. The compression format for output is determined by the **compress-format** parameter, while the compression format on input is inferred. The compression level, which is relevant only for output, is determined by the **compress-level** parameter.

replace: For output files only, replace (remove and recreate) the existing file if it exists.

exclusive: For output files only, lock the file for exclusive access. On some systems the lock is advisory, i.e., it inhibits access by other processes only if they also attempt to open exclusively.

append: For output files only, position the output port at the end of the file before each write so that output to the port is always appended to the file.

perm-set-user-id: For newly created output files under Unix-based systems only, set user-id bit.

perm-set-group-id: For newly created output files under Unix-based systems only, set group-id bit.

perm-sticky: For newly created output files under Unix-based systems only, set sticky bit.

perm-no-user-read: For newly created output files under Unix-based systems only, do not set user read bit. (User read bit is set by default, unless masked by the process umask.)

perm-no-user-write: For newly created output files under Unix-based systems only, do not set user write bit. (User write bit is set by default, unless masked by the process umask.)

perm-user-execute: For newly created output files under Unix-based systems only, set user execute bit unless masked by process umask. (User execute bit is not set by default.)

perm-no-group-read: For newly created output files under Unix-based systems only, do not set group read bit. (Group read bit is set by default, unless masked by the process umask.)

perm-no-group-write: For newly created output files under Unix-based systems only, do not set group write bit. (Group write bit is set by default, unless masked by the process umask.)

perm-group-execute: For newly created output files under Unix-based systems only, set group execute bit unless masked by process umask. (Group execute bit is not set by default.)

perm-no-other-read: For newly created output files under Unix-based systems only, do not set other read bit. (Other read bit is set by default, unless masked by the process umask.)

perm-no-other-write: For newly created output files under Unix-based systems only, do not set other write bit. (Other write bit is set by default, unless masked by the process umask.)

perm-other-execute: For newly created output files under Unix-based systems only, set other execute bit unless masked by process umask. (Other execute bit is not set by default.)
9.3. Transcoders

The language of the Revised\textsuperscript{6} Report provides three built-in codecs: a latin-1 codec, a utf-8 codec, and a utf-16 codec. \textit{Chez Scheme} provides three additional codecs: a utf-16le codec, utf-16be codec, and an “iconv” codec for non-Unicode character sets. It also provides an alternative to the standard utf-16 codec that defaults to little-endian format rather than the default big-endian format. This section describes these codecs, plus a \texttt{current-transcoder} parameter that allows the programmer to determine the transcoder used for a textual port whenever the transcoder is implicit, as for \texttt{open-input-file} or \texttt{load}, along with the predicate \texttt{transcoder?}, which should be standard but is not.

\begin{verbatim}
(utf-16-codec) procedure
(utf-16-codec endianness) procedure
(utf-16le-codec) procedure
(utf-16be-codec) procedure
returns: a codec
libraries: (chezscheme)

endianness must be the symbol \texttt{big} or the symbol \texttt{little}.

The codec returned by \texttt{utf-16-codec} can be used to create and process data written UTF-16 format. When called without the \texttt{endianness} argument or with \texttt{endianness \texttt{big}}, \texttt{utf-16-codec} returns a codec for standard UTF-16 data, i.e., one that defaults to big-endian format if no byte-order mark (BOM) is found.

When output is transcoded with a transcoder based on this codec, a BOM is emitted just before the first character written, and each character is written as a UTF-16 character in big-endian format. For input, a BOM is looked for at the start of the input and, if present, controls the byte order of the remaining UTF-16 characters. If no BOM is present, big-endian order is assumed. For input-output ports, the BOM is not emitted if the file is read before written, and a BOM is not looked for if the file is written before read.

For textual ports created via \texttt{transcoded-port}, a BOM written or read via the transcoder appears at the beginning of the underlying data stream or file only if the binary port passed to \texttt{transcoded-port} is positioned at the start of the data stream or file. When the transcoder can determine this is the case, it sets a flag that causes \texttt{set-port-position!} to position the port beyond the BOM if an attempt is made to reposition the port to the start of the data stream or file, so that the BOM is preserved.

When called with \texttt{endianness \texttt{little}}, \texttt{utf-16-codec} returns a codec that defaults to the little-endian format both for reading and for writing. For output-only streams or input/output streams that are written before read, the result is standard UTF-16, with a BOM that specifies little-endian format followed by characters in little-endian byte order. For input-only streams or input/output streams that are read before written, this codec allows programs to read from input streams that either begin with a BOM or are encoded in UTF-16LE format. This is particularly useful for handling files that might have been produced by older Windows applications that claim to produce UTF-16 files but actually produce UTF-16LE files.
The Revised^6 Report version of utf-16-codec lacks the optional endianness argument.

The codecs returned by utf-16le-codec and utf-16be-codec are used to read and write data in the UTF-16LE and UTF-16BE formats, i.e., UTF-16 with little-endian or big-endian byte order and no BOM. For output, these codecs are useful for controlling whether and where the BOM is emitted, since no BOM is emitted implicitly and a BOM can be emitted explicitly as an ordinary character. For input, these codecs are useful for processing files known to be in little-endian or big-endian format with no BOM.

```
(iconv-codec  code-page)  procedure
returns: a codec
libraries: (chezscheme)
```

code-page must be a string and should identify a codec accepted by the iconv library installed on the target machine. The codec returned by this procedure can be used to convert from the non-Unicode single- and multiple-byte character sets supported by iconv. When used in the input direction, the codec converts byte sequences into Scheme strings, and when used in the output direction, it converts Scheme strings to byte sequences.

The set of supported code pages depends on the version of iconv available; consult the iconv documentation or use the shell command `iconv --list` to obtain a list of supported code pages.

While the Windows operating system does not supply an iconv library, it is possible to use iconv-codec on Windows systems by supplying an iconv dynamic-link library (named iconv.dll, libiconv.dll, or libiconv-2.dll) that provides Posix-conformant iconv_open, iconv, and iconv_close entry points either under those names or under the alternative names libiconv_open, libiconv, and libiconv_close. The dll must be located in a standard location for dlls or in the current directory of the process the first time iconv-codec is called.

```
current-transcoder  thread parameter
libraries: (chezscheme)
```

The transcoder value of the current-transcoder parameter is used whenever a textual file is opened with an implicit transcoder, e.g., by open-input-file and other convenience I/O procedures, compile-file include, load, and pretty-file. Its initial value is the value of the native-transcoder procedure.

```
(transcoder?  obj)  procedure
returns: #t if obj is a transcoder, #f otherwise
libraries: (chezscheme)
```

```
transcoded-port-buffer-size  thread parameter
libraries: (chezscheme)
```

transcoded-port-buffer-size is a parameter that specifies the size of the string buffer that
is allocated when creating a new transcoded port. The value of this parameter must be a positive fixnum. When transcoding a binary input port that implements `port-position`, a transoded input port maintains an fvector the same size as its string buffer to support `port-position` on the transoded port.

The value of `make-codec-buffer` must be a procedure. The procedure is invoked with the binary port `bp` when `transoded-port` is called with a buffered port `bp`. The procedure must return a mutable bytevector of length at least four. The behavior of `transoded-port` and its callers is unspecified if a continuation captured within the `make-codec-buffer` procedure is invoked multiple times.

### 9.4. Port Operations

The procedures used to create, access, and alter ports directly are described in this section. Also described are several nonstandard operations on ports.

Unless otherwise specified, procedures requiring either input ports or output ports as arguments accept input/output ports as well, i.e., an input/output port is both an input port and an output port.

<table>
<thead>
<tr>
<th>procedure</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(make-input-port handler input-buffer)</code></td>
<td>procedure creates a generic port. The handler associated with the port is <code>handler</code>, the input buffer is <code>input-buffer</code>, and the output buffer is undefined.</td>
</tr>
<tr>
<td><code>(make-output-port handler output-buffer)</code></td>
<td>procedure creates a generic port. The handler associated with the port is <code>handler</code>, the input buffer is undefined, and the output buffer is <code>output-buffer</code>.</td>
</tr>
<tr>
<td><code>(make-input/output-port handler input-buffer output-buffer)</code></td>
<td>procedure creates a generic port. The handler associated with the port is <code>handler</code>, the input buffer is <code>input-buffer</code>, and the output buffer is <code>output-buffer</code>.</td>
</tr>
</tbody>
</table>

`handler` must be a procedure, and `input-buffer` and `output-buffer` must be strings. Each procedure creates a generic port. The handler associated with the port is `handler`, the input buffer is `input-buffer`, and the output buffer is `output-buffer`. For `make-input-port`, the output buffer is undefined, and for `make-output-port`, the input buffer is undefined.

The input size of an input or input/output port is initialized to the string length of the input buffer, and the input index is set to 0. The output size and index of an output or input/output port are initialized similarly.

The length of an input or output buffer may be zero, in which case buffering is effectively disabled.

<table>
<thead>
<tr>
<th>procedure</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(port-handler port)</code></td>
<td>procedure returns the handler passed to one of the generic port creation procedures described above.</td>
</tr>
</tbody>
</table>

For generic ports, `port-handler` returns the handler passed to one of the generic port creation procedures described above. For ports created by `open-input-file` and similar
procedures, \texttt{port-handler} returns an internal handler that may be invoked in the same manner as any other handler.

\begin{verbatim}
(port-input-buffer \textit{input-port}) procedure
(port-input-size \textit{input-port}) procedure
(port-input-index \textit{input-port}) procedure
(textual-port-input-buffer \textit{textual-input-port}) procedure
(textual-port-input-size \textit{textual-input-port}) procedure
(textual-port-input-index \textit{textual-input-port}) procedure
(binary-port-input-buffer \textit{binary-input-port}) procedure
(binary-port-input-size \textit{binary-input-port}) procedure
(binary-port-input-index \textit{binary-input-port}) procedure
\end{verbatim}

\texttt{returns: see below}

\texttt{libraries: (chezscheme)}

These procedures return the input buffer, size, or index of the input port. The variants specialized to textual or binary ports are slightly more efficient than their generic counterparts.

\begin{verbatim}
(set-port-input-index! \textit{input-port} \textit{n}) procedure
(set-port-input-size! \textit{input-port} \textit{n}) procedure
(set-port-input-buffer! \textit{input-port} \textit{x}) procedure
(set-textual-port-input-index! \textit{textual-input-port} \textit{n}) procedure
(set-textual-port-input-size! \textit{textual-input-port} \textit{n}) procedure
(set-textual-port-input-buffer! \textit{textual-input-port} \textit{string}) procedure
(set-binary-port-input-index! \textit{binary-input-port} \textit{n}) procedure
(set-binary-port-input-size! \textit{binary-input-port} \textit{n}) procedure
(set-binary-port-input-buffer! \textit{binary-input-port} \textit{bytevector}) procedure
\end{verbatim}

\texttt{returns: unspecified}

\texttt{libraries: (chezscheme)}

The procedure \texttt{set-port-input-index!} sets the input index field of \textit{input-port} to \textit{n}, which must be a nonnegative integer less than or equal to the port’s input size.

The procedure \texttt{set-port-input-size!} sets the input size field of \textit{input-port} to \textit{n}, which must be a nonnegative integer less than or equal to the string length of the port’s input buffer. It also sets the input index to 0.

The procedure \texttt{set-port-input-buffer!} sets the input buffer field of \textit{input-port} to \textit{x}, which must be a string for textual ports and a bytevector for binary ports. It also sets the input size to the length of the string or bytevector and the input index to 0.

The variants specialized to textual or binary ports are slightly more efficient than their generic counterparts.
These procedures return an exact integer representing the number of characters or bytes left to be read from the port’s input buffer, i.e., the difference between the buffer size and index.

The variants specialized to textual or binary ports are slightly more efficient than their generic counterpart.

This procedure determines whether the port’s input count is zero without computing or returning the actual count.

These procedures return the output buffer, size, or index of the output port. The variants specialized to textual or binary ports are slightly more efficient than their generic counterparts.
set-port-output-index! output-port n  procedure
(set-port-output-size! output-port n)  procedure
(set-port-output-buffer! output-port x)  procedure
(set-textual-port-output-index! textual-output-port n)  procedure
(set-textual-port-output-size! textual-output-port n)  procedure
(set-textual-port-output-buffer! textual-output-port string)  procedure
(set-binary-port-output-index! output-port n)  procedure
(set-binary-port-output-size! output-port n)  procedure
(set-binary-port-output-buffer! binary-output-port bytevector)  procedure

returns: unspecified
libraries: (chezscheme)

The procedure set-port-output-index! sets the output index field of the output port to
n, which must be a nonnegative integer less than or equal to the port’s output size.

The procedure set-port-output-size! sets the output size field of the output port to n,
which must be a nonnegative integer less than or equal to the string length of the port’s
output buffer. It also sets the output index to 0.

The procedure set-port-output-buffer! sets the output buffer field of output-port to x,
which must be a string for textual ports and a bytevector for binary ports. It also sets the
output size to the length of the string or bytevector and the output index to 0.

The variants specialized to textual or binary ports are slightly more efficient than their
generic counterparts.

port-output-count output-port procedure
textual-port-output-count textual-output-port procedure
binary-port-output-count binary-output-port procedure

returns: see below
libraries: (chezscheme)

These procedures return an exact integer representing the amount of space in characters
or bytes available to be written in the port’s output buffer, i.e., the difference between the
buffer size and index.

The variants specialized to textual or binary ports are slightly more efficient than their
generic counterpart.

port-output-full? output-port procedure
returns: #t if the port’s input buffer has no more room, otherwise #f
libraries: (chezscheme)

This procedure determines whether the port’s output count is zero without computing or
returning the actual count.
9.4. Port Operations

(mark-port-closed! port)  
returns: unspecified  
libraries: (chezscheme)

This procedure directly marks the port closed so that no further input or output operations are allowed on it. It is typically used by handlers upon receipt of a close-port message.

(port-closed? port)  
returns: #t if port is closed, #f otherwise  
libraries: (chezscheme)

(let ([p (open-output-string)])  
  (port-closed? p)) ⇒ #f

(let ([p (open-output-string)])  
  (close-port p)  
  (port-closed? p)) ⇒ #t

(set-port-bol! output-port obj)  
returns: unspecified  
libraries: (chezscheme)

When obj is #f, the port’s beginning-of-line (BOL) flag is cleared; otherwise, the port’s BOL flag is set.

The BOL flag is consulted by fresh-line (page 270) to determine if it needs to emit a newline. This flag is maintained automatically for file output ports, string output ports, and transcript ports. The flag is set for newly created file and string output ports, except for file output ports created with the append option, for which the flag is reset. The BOL flag is clear for newly created generic ports and never set automatically, but may be set explicitly using set-port-bol!. The port is always flushed immediately before the flag is consulted, so it need not be maintained on a per-character basis for buffered ports.

(set-port-eof! input-port obj)  
returns: unspecified  
libraries: (chezscheme)

When obj is not #f, set-port-eof! marks input-port so that, once its buffer is empty, the port is treated as if it were at eof even if more data is available in the underlying byte or character stream. Once this artificial eof has been read, the eof mark is cleared, making any additional data in the stream available beyond the eof. This feature can be used by a generic port to simulate a stream consisting of multiple input files.
When obj is ¢f, the eof mark is cleared.

The following example assumes /dev/zero provides an infinite stream of zero bytes.

(define p
  (parameterize ([file-buffer-size 3])
    (open-file-input-port "/dev/zero")))
(set-port-eof! p #t)
(get-u8 p) ⇒ ¢!eof
(get-u8 p) ⇒ 0
(set-port-eof! p #t)
(get-u8 p) ⇒ 0
(get-u8 p) ⇒ 0
(get-u8 p) ⇒ ¢!eof
(get-u8 p) ⇒ 0

(port-name port) procedure
returns: the name associated with port
libraries: (chezscheme)

The name may be any object but is usually a string or ¢f (denoting no name). For file ports, the name is typically a string naming the file.

(let ([p (open-input-file "myfile.ss")])
  (port-name p)) ⇒ "myfile.ss"

(let ([p (open-output-string)])
  (port-name p)) ⇒ "string"

(set-port-name! port obj) procedure
returns: unspecified
libraries: (chezscheme)

This procedure sets port’s name to obj, which should be a string or ¢f (denoting no name).

(port-length port) procedure
(file-length port) procedure
returns: the length of the file or other object to which port refers

(port-has-port-length? port) procedure
returns: #t if the port supports port-length, #f otherwise
libraries: (chezscheme)

A port may allow the length of the underlying stream of characters or bytes to be determined. If so, the procedure port-has-port-length? returns #t and port-length returns the current length. For binary ports, the length is always an exact nonnegative integer byte count. For textual ports, the representation of a length is unspecified; it may not be an exact nonnegative integer and, even if it is, it may not represent either a byte or character count. The length may be used at some later time to reset the length if the port
9.4. Port Operations

supports set-port-length!. If port-length is called on a port that does not support it, an exception with condition type &assertion is raised.

File lengths beyond $2^{32}$ might not be reported properly for compressed files on 32-bit versions of the system.

file-length is identical to port-length.

(set-port-length! port len) procedure
returns: unspecified
(port-has-set-port-length!? port) procedure
returns: #t if the port supports set-port-length!, #f otherwise
libraries: (chezscheme)

A port may allow the length of the underlying stream of characters or bytes to be set, i.e., extended or truncated. If so, the procedure port-has-set-port-length!? returns #t and set-port-length! changes the length. For binary ports, the length len must be an exact nonnegative integer byte count. For textual ports, the representation of a length is unspecified, as described in the entry for port-length above, but len must be an appropriate length for the textual port, which is usually guaranteed to be the case only if it was obtained from a call to port-length on the same port. If set-port-length! is called on a port that does not support it, an exception with condition type &assertion is raised.

It is not possible to set the length of a port opened with compression to an arbitrary position, and the result of an attempt to set the length of a compressed file beyond $2^{32}$ on 32-bit versions of the system is undefined.

(port-nonblocking? port) procedure
returns: #t if the port is in nonblocking mode, #f otherwise
(port-has-port-nonblocking?? port) procedure
returns: #t if the port supports port-nonblocking?, #f otherwise
libraries: (chezscheme)

A port may allow the nonblocking status of the port to be determined. If so, the procedure port-has-port-nonblocking?? returns #t and port-nonblocking? returns a boolean value reflecting whether the port is in nonblocking mode.

(set-port-nonblocking! port obj) procedure
returns: unspecified
(port-has-set-port-nonblocking!? port) procedure
returns: #t if the port supports set-port-nonblocking!, #f otherwise
libraries: (chezscheme)

A port may allow reads or writes to be performed in a “nonblocking” fashion. If so, the procedure port-has-set-port-nonblocking!? returns #t and set-port-nonblocking! sets the port to nonblocking mode (if obj is a true value) or blocking mode (if obj is #f). If set-port-nonblocking! is called on a port that does not support it, an exception with condition type &assertion is raised.
Ports created by the standard Revised\(^6\) port opening procedures are initially set in blocking mode by default. The same is true for most of the procedures described in this document. A generic port based on a nonblocking source may be nonblocking initially. A port returned by `open-fd-input-port`, `open-fd-output-port`, or `open-fd-input/output-port` is initially in nonblocking mode if the file-descriptor passed in is in nonblocking mode. Similarly, a port returned by `standard-input-port`, `standard-output-port`, or `standard-error-port` is initially in nonblocking mode if the underlying stdin, stdout, or stderr file descriptor is in nonblocking mode.

Although `get-bytevector-some` and `get-string-some` normally cannot return an empty bytevector or empty string, they can if the port is in nonblocking mode and no input is available. Also, `get-bytevector-some!` and `get-string-some!` may not read any data if the port is in nonblocking mode and no data is available. Similarly, `put-bytevector-some` and `put-string-some` may not write any data if the port is in nonblocking mode and no room is available.

Nonblocking mode is not supported under Windows.

```
(file-position port) procedure
(file-position port pos) procedure
returns: see below
libraries: (chezscheme)
```

When the second argument is omitted, this procedure behaves like the R6RS `port-position` procedure, and when present, like the R6RS `set-port-position!` procedure.

For compressed files opened with the `compressed` flag, `file-position` returns the position in the uncompressed stream of data. Changing the position of a compressed input file opened with the `compressed` flag generally requires rewinding and rereading the file and might thus be slow. The position of a compressed output file opened with the `compressed` flag can be moved forward only; this is accomplished by writing a (compressed) sequence of zeros. File positions beyond \(2^{32}\) might not be reported properly for compressed files on 32-bit versions of the system.

```
(clear-input-port) procedure
(clear-input-port input-port) procedure
returns: unspecified
libraries: (chezscheme)
```

If `input-port` is not supplied, it defaults to the current input port. This procedure discards any data in the buffer associated with `input-port`. This may be necessary, for example, to clear any type-ahead from the keyboard in preparation for an urgent query.
9.4. Port Operations

(clear-output-port) procedure
(clear-output-port output-port) procedure
returns: unspecified
libraries: (chezscheme)

If output-port is not supplied, it defaults to the current output port. This procedure discards any data in the buffer associated with output-port. This may be necessary, for example, to clear any pending output on an interactive port in preparation for an urgent message.

(flush-output-port) procedure
(flush-output-port output-port) procedure
returns: unspecified
libraries: (chezscheme)

If output-port is not supplied, it defaults to the current output port. This procedure forces any data in the buffer associated with output-port to be printed immediately. The console output port is automatically flushed after a newline and before input from the console input port; all ports are automatically flushed when they are closed. flush-output-port may be necessary, however, to force a message without a newline to be sent to the console output port or to force output to appear on a file without delay.

(port-file-compressed! port) procedure
returns: unspecified
libraries: (chezscheme)

port must be an input or an output port, but not an input/output port. It must be a file port pointing to a regular file, i.e., a file on disk rather than, e.g., a socket. The port can be a binary or textual port. If the port is an output port, subsequent output sent to the port will be compressed. If the port is an input port, subsequent input will be decompressed if and only if the port is currently pointing at compressed data. The compression format for output is determined by the compress-format parameter, while the compression format on input is inferred. The compression level, which is relevant only for output, is determined by the compress-level parameter. This procedure has no effect if the port is already set for compression.

compress-format thread parameter
libraries: (chezscheme)

compress-format determines the compression algorithm and format used for output. Currently, the possible values of the parameter are the symbols lz4 (the default) and gzip.

The lz4 format uses the LZ4 compression library developed by Yann Collet. It is therefore compatible with the lz4 program, which means that lz4 may be used to uncompress files produced by Chez Scheme and visa versa.
The gzip format uses the zlib compression library developed by Jean-loup Gailly and Mark Adler. It is therefore compatible with the gzip program, which means that gzip may be used to uncompress files produced by Chez Scheme and visa versa.

Reading lz4-compressed data tends to be much faster than reading gzip-compressed data, while gzip-compressed data tends to be significantly smaller.

<table>
<thead>
<tr>
<th>compress-level</th>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

compress-level determines the amount of effort spent on compression and is thus relevant only for output. It can be set to one of the symbols minimum, low, medium, high, or maximum, which are listed in order from shortest to longest expected compression time and least to greatest expected effectiveness. Its default value is medium.

9.5. String Ports

String ports allow the creation and manipulation of strings via port operations. The procedure open-input-string converts a string into a textual input port, allowing the characters in the string to be read in sequence via input operations such as read-char or read. The procedure open-output-string allows new strings to be built up with output operations such as write-char and write.

While string ports could be defined as generic ports, they are instead supported as primitive by the implementation.

(open-input-string string) procedure
returns: a new string input port
libraries: (chezscheme)

A string input port is similar to a file input port, except that characters and objects drawn from the port come from string rather than from a file.

A string port is at “end of file” when the port reaches the end of the string. It is not necessary to close a string port, although it is okay to do so.

(let ([p (open-input-string "hi mom!")])
  (let ([x (read p)])
    (list x (read p)))) ⇒ (hi mom!)

(with-input-from-string string thunk) procedure
returns: the values returned by thunk
libraries: (chezscheme)

thunk must be a procedure and should accept zero arguments. with-input-from-string parameterizes the current input port to be the result of opening string for input during the application of thunk.
(with-input-from-string "(cons 3 4)"
  (lambda ()
    (eval (read)))) ⇒ (3 . 4)

(open-output-string)
returns: a new string output port
libraries: (chezscheme)

A string output port is similar to a file output port, except that characters and objects written to the port are placed in a string (which grows as needed) rather than to a file. The string built by writing to a string output port may be obtained with get-output-string. See the example given for get-output-string below. It is not necessary to close a string port, although it is okay to do so.

(get-output-string string-output-port)
returns: the string associated with string-output-port
libraries: (chezscheme)

string-output-port must be an port returned by open-output-string.

As a side effect, get-output-string resets string-output-port so that subsequent output to string-output-port is placed into a fresh string.

(let ([p (open-output-string)])
  (write 'hi p)
  (write-char #\space p)
  (write 'mom! p)
  (get-output-string p)) ⇒ "hi mom!"

An implementation of format (Section 9.13) might be written using string-output ports to produce string output.

(with-output-to-string thunk)
returns: a string containing the output
libraries: (chezscheme)

thunk must be a procedure and should accept zero arguments. with-output-to-string parameterizes the current output port to a new string output port during the application of thunk. If thunk returns, the string associated with the new string output port is returned, as with get-output-string.

(with-output-to-string
  (lambda ()
    (display "Once upon a time ...")
    (newline))) ⇒ "Once upon a time ...
"
9.6. File Ports

`file-buffer-size` thread parameter

`file-buffer-size` is a parameter that determines the size of each buffer created when the buffer mode is not `none` for a port created by one of the file open operations, e.g., `open-input-file` or `open-file-output-port`. The value of this parameter must be a positive fixnum.

```
(file-port? port)
```

procedure

returns: `#t` if `port` is a file port, `#f` otherwise

libraries: (chezscheme)

A file port is any port based directly on an O/S file descriptor, e.g., one created by `open-file-input-port`, `open-output-port`, `open-fd-input-port`, etc., but not a string, bytevector, or custom port.

```
(port-file-descriptor port)
```

procedure

returns: the file descriptor associated with `port`

libraries: (chezscheme)

`port` must be a file port, i.e., a port for which `file-port?` returns `#t`.

9.7. Custom Ports

`custom-port-buffer-size` thread parameter

`custom-port-buffer-size` is a parameter that determines the sizes of the buffers associated with newly created custom ports. The value of this parameter must be a positive fixnum.

9.8. Input Operations

`console-input-port` global parameter

`console-input-port` is a parameter that determines the input port used by the waiter and interactive debugger. When called with no arguments, it returns the console input port. When called with one argument, which must be a textual input port, it changes the value of the console input port. The initial value of this parameter is a port tied to the standard input (stdin) stream of the Scheme process.
9.8. Input Operations

`current-input-port` is a parameter that determines the default port argument for most input procedures, including `read-char`, `peek-char`, and `read`. When called with no arguments, `current-input-port` returns the current input port. When called with one argument, which must be a textual input port, it changes the value of the current input port. The Revised\textsuperscript{6} Report version of `current-input-port` accepts only zero arguments, i.e., it cannot be used to change the current input port. The initial value of this parameter is the same port as the initial value of `console-input-port`.

```lisp
(open-input-file path)  procedure
(open-input-file path options) procedure
returns: a new input port
libraries: (chezscheme)
```

`path` must be a string. `open-input-file` opens a textual input port for the file named by `path`. An exception is raised with condition type `&i/o-filename` if the file does not exist or cannot be opened for input.

`options`, if present, is a symbolic option name or option list. Possible symbolic option names are `compressed`, `uncompressed`, `buffered`, and `unbuffered`. An option list is a list containing zero or more symbolic option names.

The mutually exclusive `compressed` and `uncompressed` options determine whether the input file should be decompressed if it is compressed (where the compression format is inferred). (See `open-output-file`.) The default is `uncompressed`, so the `uncompressed` option is useful only as documentation.

The mutually exclusive `buffered` and `unbuffered` options determine whether input is buffered. When input is buffered, it is read in large blocks and buffered internally for efficiency to reduce the number of operating system requests. When the `unbuffered` option is specified, input is unbuffered, but not fully, since one character of buffering is required to support `peek-char` and `unread-char`. Input is buffered by default, so the `buffered` option is useful only as documentation.

For example, the call

```
(open-input-file "frob" '(compressed))
```

opens the file frob with decompression enabled.

The Revised\textsuperscript{6} Report version of `open-input-file` does not support the optional `options` argument.
(call-with-input-file path procedure)
returns: the values returned by procedure
libraries: (chezscheme)

(path must be a string. procedure should accept one argument.)
call-with-input-file creates a new input port for the file named by path, as if with open-input-file, and passes this port to procedure. If procedure returns normally, call-with-input-file closes the input port and returns the values returned by procedure.
call-with-input-file does not automatically close the input port if a continuation created outside of procedure is invoked, since it is possible that another continuation created inside of procedure will be invoked at a later time, returning control to procedure. If procedure does not return, an implementation is free to close the input port only if it can prove that the input port is no longer accessible. As shown in Section 5.6 of The Scheme Programming Language, 4th Edition, dynamic-wind may be used to ensure that the port is closed if a continuation created outside of procedure is invoked.
See open-input-file above for a description of the optional options argument.
The Revised6 Report version of call-with-input-file does not support the optional input argument.

(with-input-from-file path thunk)
returns: the values returned by thunk
libraries: (chezscheme)

(path must be a string. thunk must be a procedure and should accept zero arguments.)
with-input-from-file temporarily changes the current input port to be the result of opening the file named by path, as if with open-input-file, during the application of thunk. If thunk returns, the port is closed and the current input port is restored to its old value.
The behavior of with-input-from-file is unspecified if a continuation created outside of thunk is invoked before thunk returns. An implementation may close the port and restore the current input port to its old value—but it may not.
See open-input-file above for a description of the optional options argument.
The Revised6 Report version of with-input-from-file does not support the optional options argument.

(open-fd-input-port fd)
returns: a new input port for the file descriptor fd
libraries: (chezscheme)

(fd must be a nonnegative exact integer and should be a valid open file descriptor. If ?transcoder is present and not #f, it must be a transcoder, and this procedure returns a
textual input port whose transcoder is `transcoder`. Otherwise, this procedure returns a binary input port. See the lead-in to Section 7.2 of *The Scheme Programming Language, 4th Edition* for a description of the constraints on and effects of the other arguments.

The file descriptor is closed when the port is closed.

```
(standard-input-port) procedure
(standard-input-port b-mode) procedure
(standard-input-port b-mode ?transcoder) procedure
```

returns: a new input port connected to the process’s standard input
libraries: (chezscheme)

If `transcoder` is present and not `#f`, it must be a transcoder, and this procedure returns a textual input port whose transcoder is `transcoder`. Otherwise, this procedure returns a binary input port. The buffer mode `b-mode` defaults to `block`.

The Revised\(^6\) Report version of this procedure does not accept the optional `b-mode` and `?transcoder` arguments, which limits it to an implementation-dependent buffering mode (`block` in Chez Scheme) and binary output.

```
(get-string-some textual-input-port) procedure
returns: a nonempty string or the eof object
libraries: (chezscheme)
```

If `textual-input-port` is at end of file, the eof object is returned. Otherwise, `get-string-some` reads (as if with `get-u8`) at least one character and possibly more, and returns a string containing these characters. The port’s position is advanced past the characters read. The maximum number of characters read by this operation is implementation-dependent.

An exception to the “at least one character” guarantee occurs if the port is in nonblocking mode (see `set-port-nonblocking!`) and no input is ready. In this case, an empty string is returned.

```
(get-string-some! textual-input-port string start n) procedure
returns: the count of characters read, as an exact nonnegative integer, or the eof object
libraries: (chezscheme)
```

`start` and `n` must be exact nonnegative integers, and the sum of `start` and `n` must not exceed the length of `string`.

If `n` is 0, this procedure returns zero without attempting to read from `textual-input-port` and without modifying `string`.

Otherwise, if `textual-input-port` is at end of file, this procedure returns the eof object, except it returns zero when the port is in nonblocking mode (see `set-port-nonblocking!`) and the port cannot be determined to be at end of file without blocking. In either case, `string` is not modified.
Otherwise, this procedure reads (as if with `get-char`) up to \( n \) characters from the port, stores the characters in consecutive locations of `string` starting at `start`, advances the port’s position just past the characters read, and returns the count of characters read.

If the port is in nonblocking mode, this procedure reads no more than it can without blocking and thus might read zero characters; otherwise, it reads at least one character but no more than are available when the first character becomes available.

\[
\text{(get-bytevector-some! binary-input-port bytevector start n)}
\]

procedure
returns: the count of bytes read, as an exact nonnegative integer, or the eof object

libraries: (chezscheme)

`start` and `n` must be exact nonnegative integers, and the sum of `start` and `n` must not exceed the length of `bytevector`.

If `n` is 0, this procedure returns zero without attempting to read from `binary-input-port` and without modifying `bytevector`.

Otherwise, if `binary-input-port` is at end of file, this procedure returns the eof object, except it returns zero when the port is in nonblocking mode (see `set-port-nonblocking!`) and the port cannot be determined to be at end of file without blocking. In either case, `bytevector` is not modified.

Otherwise, this procedure reads (as if with `get-u8`) up to `n` bytes from the port, stores the bytes in consecutive locations of `bytevector` starting at `start`, advances the port’s position just past the bytes read, and returns the count of bytes read.

If the port is in nonblocking mode, this procedure reads no more than it can without blocking and thus might read zero bytes; otherwise, it reads at least one byte but no more than are available when the first byte becomes available.

\[
\begin{align*}
(\text{unread-char} & \ char) \\
(\text{unread-char} & \ char \ textual-input-port) \\
(\text{unget-char} & \ textual-input-port \ char)
\end{align*}
\]

procedure
returns: unspecified

libraries: (chezscheme)

For `unread-char`, if `textual-input-port` is not supplied, it defaults to the current input port. These procedures “unread” the last character read from `textual-input-port`. `char` may or may not be ignored, depending upon the implementation. In any case, `char` should be the last character read from the port. A character should not be unread twice on the same port without an intervening call to `read-char` or `get-char`.

`unread-char` and `unget-char` are provided for applications requiring one character of lookahead and may be used in place of, or even in combination with, `peek-char` or `lookahead-char`. One character of lookahead is required in the procedure `read-word`, which is defined below in terms of `unread-char`. `read-word` returns the next word from a textual input port as a string, where a word is defined to be a sequence of alphabetic characters. Since it does not know until it reads one character too many that it has read the entire word, `read-word` uses `unread-char` to return the character to the input port.
(define read-word
  (lambda (p)
    (list->string
      (let f ([c (read-char p)])
        (cond
          [(eof-object? c) '()]  
          [(char-alphabetic? c)
            (cons c (f (read-char p)))]
          [else
            (unread-char c p)
            '()])))
      ))))

In the alternate version below, peek-char is used instead of unread-char.

(define read-word
  (lambda (p)
    (list->string
      (let f ([c (peek-char p)])
        (cond
          [(eof-object? c) '()]  
          [(char-alphabetic? c)
            (read-char p)
            (cons c (f (peek-char p)))]
          [else '()])))
      ))))

The advantage of unread-char in this situation is that only one call to unread-char per word is required, whereas one call to peek-char is required for each character in the word plus the first character beyond. In many cases, unread-char and unget-char do not enjoy this advantage, and peek-char or lookahead-char should be used instead.

(unget-u8  binary-input-port  octet)  procedure
returns: unspecified
libraries: (chezscheme)

This procedures “unreads” the last byte read from binary-input-port. octet may or may not be ignored, depending upon the implementation. In any case, octet should be last byte read from the port. A byte should not be unread twice on the same port without an intervening call to get-u8.

(input-port-ready?  input-port)  procedure
returns: #t if data is available on input-port, #f otherwise
libraries: (chezscheme)

input-port-ready? allows a program to check to see if input is available on a textual or binary input port without hanging. If input is available or the port is at end of file, input-port-ready? returns #t. If it cannot determine from the port whether input is ready, input-port-ready? raises an exception with condition type i/o-read-error. Otherwise, it returns #f.
(char-ready?) \text{procedure}
(char-ready? \text{textual-input-port}) \text{procedure}
\text{returns: } \#t \text{ if a character is available on } \text{textual-input-port}, \#f \text{ otherwise}
\text{libraries: (chezscheme)}

If \text{textual-input-port} is not supplied, it defaults to the current input port. \text{char-ready?} is like \text{input-port-ready?} except it is restricted to textual input ports.

(block-read \text{textual-input-port} \text{string}) \text{procedure}
(block-read \text{textual-input-port} \text{string} \text{count}) \text{procedure}
\text{returns: see below}
\text{libraries: (chezscheme)}

\text{count} \text{ must be a nonnegative fixnum less than or equal to the length of } \text{string}. \text{ If not provided, it defaults to the length of } \text{string}.

If \text{textual-input-port} is at end-of-file, an eof object is returned. Otherwise, \text{string} is filled with as many characters as are available for reading from \text{textual-input-port} up to \text{count}, and the number of characters placed in the string is returned.

If \text{textual-input-port} is buffered and the buffer is nonempty, the buffered input or a portion thereof is returned; otherwise \text{block-read} bypasses the buffer entirely.

(read-token) \text{procedure}
(read-token \text{textual-input-port}) \text{procedure}
(read-token \text{textual-input-port} \text{sfd} \text{bfp}) \text{procedure}
\text{returns: see below}
\text{libraries: (chezscheme)}

\text{sfd} \text{ must be a source-file descriptor. } \text{bfp} \text{ must be an exact nonnegative integer and should be the character position of the next character to be read from } \text{textual-input-port}.\n
Parsing of a Scheme datum is conceptually performed in two steps. First, the sequence of characters that form the datum are grouped into \text{tokens}, such as symbols, numbers, left parentheses, and double quotes. During this first step, whitespace and comments are discarded. Second, these tokens are grouped into data.

\text{read} performs both of these steps and creates an internal representation of each datum it parses. \text{read-token} may be used to perform the first step only, one token at a time. \text{read-token} is intended to be used by editors and program formatters that must be able to parse a program or datum without actually reading it.

If \text{textual-input-port} is not supplied, it defaults to the current input port. One token is read from the input port and returned as four values:

\text{type}: a symbol describing the type of token read,
\text{value}: the token value,
\text{start}: the position of the first character of the token, relative to the starting position of the input port (or \#f, if the position cannot be determined), and
9.8. Input Operations 263

end: the first position beyond the token, relative to the starting position of the input port (or #f, if the position cannot be determined).

The input port is left pointing to the first character position beyond the token.

When the token type fully specifies the token, read-token returns #f for the value. The token types are listed below with the corresponding value in parentheses.

atomic (atom) an atomic value, i.e., a symbol, boolean, number, character, #!eof, or #!bwp
box (#f) box prefix, i.e., #&
dot (#f) dotted pair separator, i.e., .
eof (#!eof) end of file
fasl (#f) fasl prefix, i.e., #@
insert (n) graph reference, i.e., #n#
lbrack (#f) open square bracket
lparen (#f) open parenthesis
mark (n) graph mark, i.e., #n=
quote (quote, quasiquote, syntax, unquote, unquote-splicing, or datum-comment) an abbreviation mark, e.g., ' or ,@ or datum-comment prefix
rbrack (#f) close square bracket
record-brack (#f) record open bracket, i.e., #[
rparen (#f) close parenthesis
vfxnparen (n) fxvector prefix, i.e., #nvfx(
vfxparen (#f) fxvector prefix, i.e., #vfx(
vnparen (n) vector prefix, i.e., #n(
vparen (#f) vector prefix, i.e., #(
vu8nparen (n) bytevector prefix, i.e., #nvu8(
vu8paren (#f) bytevector prefix, i.e., #vu8(

The set of token types is likely to change in future releases of the system; check the release notes for details on such changes.

Specifying sfd and bfp improves the quality of error messages, guarantees start and end can be determined, and eliminates the overhead of asking for a file position on each call to read-token. In most cases, bfp should be 0 for the first call to read-token at the start of a file, and it should be the fourth return value (end) of the preceding call to read-token for each subsequent call. This protocol is necessary to handle files containing multiple-byte characters, since file positions do not necessarily correspond to character positions.

(define s (open-input-string "(a b c)"))
(read-token s) ⇒ lparen
    #f
    0
    1
(define s (open-input-string "abc 123"))
(read-token s) ⇒ atomic
  abc
  0
  3

(define s (open-input-string ""))
(read-token s) ⇒ eof
  #!eof
  0
  0

(define s (open-input-string "#7=#7#"))
(read-token s) ⇒ mark
  7
  0
  3

(read-token s) ⇒ insert
  7
  3
  6

The information read-token returns is not always sufficient for reconstituting the exact sequence of characters that make up a token. For example, 1.0 and 1e0 both return type atomic with value 1.0. The exact sequence of characters may be obtained only by repositioning the port and reading a block of characters of the appropriate length, using the relative positions given by start and end.

9.9. Output Operations

console-output-port  global parameter
libraries: (chezscheme)

console-output-port is a parameter that determines the output port used by the waiter and interactive debugger. When called with no arguments, it returns the console output port. When called with one argument, which must be a textual output port, it changes the value of the console output port. The initial value of this parameter is a port tied to the standard output (stdout) stream of the Scheme process.

current-output-port  thread parameter
libraries: (chezscheme)

current-output-port is a parameter that determines the default port argument for most output procedures, including write-char, newline, write, display, and pretty-print. When called with no arguments, current-output-port returns the current output port. When called with one argument, which must be a textual output port, it changes the value of the current output port. The Revised Edition Report version of current-output-port accepts only zero arguments, i.e., it cannot be used to change the current output port. The initial value of this parameter is the same port as the initial value of console-output-port.
console-error-port is a parameter that can be used to set or obtain the console error port, which determines the port to which conditions and other messages are printed by the default exception handler. When called with no arguments, console-error-port returns the console error port. When called with one argument, which must be a textual output port, it changes the value of the console error port.

If the system determines that the standard output (stdout) and standard error (stderr) streams refer to the same file, socket, pipe, virtual terminal, device, etc., this parameter is initially set to the same value as the parameter console-output-port. Otherwise, this parameter is initially set to a different port tied to the standard error (stderr) stream of the Scheme process.

current-error-port is a parameter that can be used to set or obtain the current error port. When called with no arguments, current-error-port returns the current error port. When called with one argument, which must be a textual output port, it changes the value of the current error port. The Revised Report version of current-error-port accepts only zero arguments, i.e., it cannot be used to change the current error port. The initial value of this parameter is the same port as the initial value of console-error-port.

(open-output-file path) procedure
(open-output-file path options) procedure
returns: a new output port
libraries: (chezscheme)

path must be a string. open-output-file opens a textual output port for the file named by path.

options, if present, is a symbolic option name or option list. Possible symbolic option names are error, truncate, replace, append, compressed, uncompressed, buffered, unbuffered, exclusive, and nonexclusive. An option list is a list containing zero or more symbolic option names and possibly the two-element option mode mode.

The mutually exclusive error, truncate, replace, and append options are used to direct what happens when the file to be opened already exists.

error: An exception is raised with condition-type &i/o-filename.
replace: The existing file is deleted before the new file is opened.
truncate: The existing file is opened and truncated to zero length.
append: The existing file is opened and the output port is positioned at the end of the file before each write so that output to the port is always appended to the file.

The default behavior is to raise an exception.
The mutually exclusive **compressed** and **uncompressed** options determine whether the output file is to be compressed. The compression format and level are determined by the **compress-format** and **compress-level** parameters. Files are uncompressed by default, so the **uncompressed** option is useful only as documentation.

The mutually exclusive **buffered** and **unbuffered** options determine whether output is buffered. Unbuffered output is sent immediately to the file, whereas buffered output not written until the port’s output buffer is filled or the port is flushed (via **flush-output-port**) or closed (via **flush-output-port** or by the storage management system when the port becomes inaccessible). Output is buffered by default for efficiency, so the **buffered** option is useful only as documentation.

The mutually exclusive **exclusive** and **nonexclusive** options determine whether access to the file is “exclusive.” When the exclusive option is specified, the file is locked until the port is closed to prevent access by other processes. On some systems the lock is advisory, i.e., it inhibits access by other processes only if they also attempt to open exclusively. Nonexclusive access is the default, so the **nonexclusive** option is useful only as documentation.

The **mode** option determines the permission bits on Unix systems when the file is created by the operation, subject to the process umask. The subsequent element in the options list must be an exact integer specifying the permissions in the manner of the Unix **open** function. The mode option is ignored under Windows.

For example, the call

```
(open-output-file "frob" '(compressed truncate mode #o644))
```

opens the file frob with compression enabled. If frob already exists it is truncated. On Unix-based systems, if frob does not already exist, the permission bits on the newly created file are set to logical and of #o644 and the process’s umask.

The Revised\(^6\) Report version of **open-output-file** does not support the optional **options** argument.

```
(call-with-output-file path procedure) procedure
(call-with-output-file path procedure options) procedure
```

returns: the values returned by **procedure**

libraries: (chezscheme)

**path** must be a string. **procedure** should accept one argument.

**call-with-output-file** creates a new output port for the file named by **path**, as if with **open-output-file**, and passes this port to **procedure**. If **procedure** returns, **call-with-output-file** closes the output port and returns the values returned by **procedure**.

**call-with-output-file** does not automatically close the output port if a continuation created outside of **procedure** is invoked, since it is possible that another continuation created inside of **procedure** will be invoked at a later time, returning control to **procedure**. If **procedure** does not return, an implementation is free to close the output port only if it can prove that the output port is no longer accessible. As shown in Section 5.6 of *The Scheme
Programming Language, 4th Edition, dynamic-wind may be used to ensure that the port is closed if a continuation created outside of procedure is invoked.

See open-output-file above for a description of the optional options argument.

The Revised 6 Report version of call-with-output-file does not support the optional options argument.

(with-output-to-file path thunk) procedure
(with-output-to-file path thunk options) procedure
returns: the value returned by thunk
libraries: (chezscheme)

path must be a string. thunk must be a procedure and should accept zero arguments.

with-output-to-file temporarily rebinds the current output port to be the result of opening the file named by path, as if with open-output-file, during the application of thunk. If thunk returns, the port is closed and the current output port is restored to its old value.

The behavior of with-output-to-file is unspecified if a continuation created outside of thunk is invoked before thunk returns. An implementation may close the port and restore the current output port to its old value—but it may not.

See open-output-file above for a description of the optional options argument.

The Revised 6 Report version of with-output-to-file does not support the optional options argument.

(open-fd-output-port fd) procedure
(open-fd-output-port fd b-mode) procedure
(open-fd-output-port fd b-mode ?transcoder) procedure
returns: a new output port for the file descriptor fd
libraries: (chezscheme)

fd must be a nonnegative exact integer and should be a valid open file descriptor. If ?transcoder is present and not #f, it must be a transcoder, and this procedure returns a textual output port whose transcoder is ?transcoder. Otherwise, this procedure returns a binary output port. See the lead-in to Section 7.2 of The Scheme Programming Language, 4th Edition for a description of the constraints on and effects of the other arguments.

The file descriptor is closed when the port is closed.

(standard-output-port) procedure
(standard-output-port b-mode) procedure
(standard-output-port b-mode ?transcoder) procedure
returns: a new output port connected to the process’s standard output
libraries: (chezscheme)

If ?transcoder is present and not #f, it must be a transcoder, and this procedure returns a textual output port whose transcoder is ?transcoder. Otherwise, this procedure returns a
binary output port. The buffer mode $b$-mode defaults to line, which differs from block in Chez Scheme only for textual output ports.

The Revised$^6$ Report version of this procedure does not accept the optional $b$-mode and $\texttt{?transcoder}$ arguments, which limits it to an implementation-dependent buffering mode (line in Chez Scheme) and binary output.

\begin{itemize}
  \item [(standard-error-port)] \textit{procedure} \hfill returns: a new output port connected to the process’s standard error
  \item [(standard-error-port $b$-mode)] \textit{procedure} \hfill libraries: (chezscheme)
  \item [(standard-error-port $b$-mode $\texttt{?transcoder}$)] \textit{procedure}
\end{itemize}

If $\texttt{?transcoder}$ is present and not $\texttt{#f}$, it must be a transcoder, and this procedure returns a textual output port whose transcoder is $\texttt{?transcoder}$. Otherwise, this procedure returns a binary output port. The buffer mode $b$-mode defaults to $\texttt{none}$. See the lead-in to Section 7.2 of The Scheme Programming Language, 4th Edition for a description of the constraints on and effects of the other arguments.

The Revised$^6$ Report version of this procedure does not accept the optional $b$-mode and $\texttt{?transcoder}$ arguments, which limits it to an implementation-dependent buffering mode (none in Chez Scheme) and binary output.

\begin{itemize}
  \item [(put-bytevector-some $\textit{binary-output-port}$ $\textit{bytevector}$)] \textit{procedure} \hfill returns: the number of bytes written
  \item [(put-bytevector-some $\textit{binary-output-port}$ $\textit{bytevector} \textit{start}$)] \textit{procedure}
  \item [(put-bytevector-some $\textit{binary-output-port}$ $\textit{bytevector} \textit{start}$ $\textit{n}$)] \textit{procedure}
\end{itemize}

$\textit{start}$ and $\textit{n}$ must be nonnegative exact integers, and the sum of $\textit{start}$ and $\textit{n}$ must not exceed the length of $\textit{bytevector}$. If not supplied, $\textit{start}$ defaults to zero and $\textit{n}$ defaults to the difference between the length of $\textit{bytevector}$ and $\textit{start}$.

This procedure normally writes the $\textit{n}$ bytes of $\textit{bytevector}$ starting at $\textit{start}$ to the port and advances its position past the end of the bytes written. If the port is in nonblocking mode (see set-port-nonblocking!), however, the number of bytes written may be less than $\textit{n}$, if the system would have to block to write more bytes.

\begin{itemize}
  \item [(put-string-some $\textit{textual-output-port}$ $\textit{string}$)] \textit{procedure} \hfill libraries: (chezscheme)
  \item [(put-string-some $\textit{textual-output-port}$ $\textit{string} \textit{start}$)] \textit{procedure}
  \item [(put-string-some $\textit{textual-output-port}$ $\textit{string} \textit{start}$ $\textit{n}$)] \textit{procedure}
\end{itemize}

$\textit{start}$ and $\textit{n}$ must be nonnegative exact integers, and the sum of $\textit{start}$ and $\textit{n}$ must not exceed the length of $\textit{string}$. If not supplied, $\textit{start}$ defaults to zero and $\textit{n}$ defaults to the difference between the length of $\textit{string}$ and $\textit{start}$.
This procedure normally writes the \( n \) characters of \textit{string} starting at \textit{start} to the port and advances the its position past the end of the characters written. If the port is in nonblocking mode (see \texttt{set-port-nonblocking!}), however, the number of characters written may be less than \( n \), if the system would have to block to write more characters.

\textbf{(display-string \textit{string})} \hspace{1cm} \textbf{procedure}
\textbf{(display-string \textit{string} \textit{textual-output-port})} \hspace{1cm} \textbf{procedure}
\textbf{returns:} unspecified
\textbf{libraries:} (chezscheme)

\textbf{display-string} writes the characters contained within \textit{string} to \textit{textual-output-port} or to the current-output port if \textit{textual-output-port} is not specified. The enclosing string quotes are not printed, and special characters within the string are not escaped. \textbf{display-string} is a more efficient alternative to \textbf{display} for displaying strings.

\textbf{(block-write \textit{textual-output-port} \textit{string})} \hspace{1cm} \textbf{procedure}
\textbf{(block-write \textit{textual-output-port} \textit{string} \textit{count})} \hspace{1cm} \textbf{procedure}
\textbf{returns:} unspecified
\textbf{libraries:} (chezscheme)

\textit{count} must be a nonnegative fixnum less than or equal to the length of \textit{string}. If not provided, it defaults to the length of \textit{string}.

\textbf{block-write} writes the first \textit{count} characters of \textit{string} to \textit{textual-output-port}. If the port is buffered and the buffer is nonempty, the buffer is flushed before the contents of \textit{string} are written. In any case, the contents of \textit{string} are written immediately, without passing through the buffer.

\textbf{(truncate-port \textit{output-port})} \hspace{1cm} \textbf{procedure}
\textbf{(truncate-port \textit{output-port} \textit{pos})} \hspace{1cm} \textbf{procedure}
\textbf{(truncate-file \textit{output-port})} \hspace{1cm} \textbf{procedure}
\textbf{(truncate-file \textit{output-port} \textit{pos})} \hspace{1cm} \textbf{procedure}
\textbf{returns:} unspecified
\textbf{libraries:} (chezscheme)

\textbf{truncate-port} and \textbf{truncate-file} are identical.

\textit{pos} must be an exact nonnegative integer. It defaults to 0.

These procedures truncate the file or other object associated with \textit{output-port} to \textit{pos} and repositions the port to that position, i.e., it combines the functionality of \texttt{set-port-length!} and \texttt{set-port-position!} and can be called on a port only if \texttt{port-has-set-port-length!?} and \texttt{port-has-set-port-position!?} are both true of the port.
If `textual-output-port` is not supplied, it defaults to the current output port. This procedure behaves like `newline`, i.e., sends a newline character to `textual-output-port`, unless it can determine that the port is already positioned at the start of a line. It does this by flushing the port and consulting the “beginning-of-line” (BOL) flag associated with the port. (See page 249.)

### 9.10. Input/Output Operations

```scheme
(open-input-output-file path)
(open-input-output-file path options)
returns: a new input-output port
libraries: (chezscheme)
```

`path` must be a string. `open-input-output-file` opens a textual input-output port for the file named by `path`.

The port may be used to read from or write to the named file. The file is created if it does not already exist.

`options`, if present, is a symbolic option name or option list. Possible symbolic option names are `buffered`, `unbuffered`, `exclusive`, and `nonexclusive`. An option list is a list containing zero or more symbolic option names and possibly the two-element option `mode mode`. See the description of `open-output-file` for an explanation of these options.

Input/output files are usually closed using `close-port` but may also be closed with either `close-input-port` or `close-output-port`.

```scheme
(open-fd-input/output-port fd)
(open-fd-input/output-port fd b-mode)
(open-fd-input/output-port fd b-mode ?transcoder)
returns: a new input/output port for the file descriptor `fd`
libraries: (chezscheme)
```

`fd` must be a nonnegative exact integer and should be a valid open file descriptor. If `?transcoder` is present and not `#f`, it must be a transcoder, and this procedure returns a textual input/output port whose transcoder is `?transcoder`. Otherwise, this procedure returns a binary input/output port. See the lead-in to Section 7.2 of *The Scheme Programming Language, 4th Edition* for a description of the constraints on and effects of the other arguments.

The file descriptor is closed when the port is closed.
9.11. Non-Unicode Bytevector/String Conversions

The procedures described in this section convert bytevectors containing single- and multiple-byte sequences in non-Unicode character sets to and from Scheme strings. They are available only under Windows. Under other operating systems, and when an iconv DLL is available under Windows, bytevector->string and string->bytevector can be used with a transcoder based on a codec constructed via iconv-codec to achieve the same results, with more control over the handling of invalid characters and line endings.

\[
\begin{align*}
\text{(multibyte->string } & \text{ code-page } \text{ bytevector)} \\
\text{return: a string containing the characters encoded in } & \text{bytevector} \\
\text{(string->multibyte } & \text{ code-page } \text{ string)} \\
\text{return: a bytevector containing the encodings of the characters in } & \text{string}
\end{align*}
\]

These procedures are available only under Windows. The procedure multibyte->string is a wrapper for the Windows API MultiByteToWideChar function, and string->multibyte is a wrapper for the Windows API WideCharToMultiByte function.

code-page declares the encoding of the byte sequences in the input or output bytevectors. It must be an exact nonnegative integer identifying a code page or one of the symbols cp-acp, cp-maccp, cp-oemcp, cp-symbol, cp-thread-acp, cp-utf7, or cp-utf8, which have the same meanings as the API function meanings for the like-named constants.

9.12. Pretty Printing

The pretty printer is a version of the write procedure that produces more human-readable output via introduced whitespace, i.e., line breaks and indentation. The pretty printer is the default printer used by the read-eval-print loop (waiter) to print the output(s) of each evaluated form. The pretty printer may also be invoked explicitly by calling the procedure pretty-print.

The pretty printer’s operation can be controlled via the pretty-format procedure described later in this section, which allows the programmer to specify how specific forms are to be printed, various pretty-printer controls, also described later in this section, and also by the generic input/output controls described in Section 9.14.

\[
\begin{align*}
\text{(pretty-print } & \text{ obj)} \\
\text{return: unspecified} \\
\text{(pretty-print } & \text{ obj textual-output-port)} \\
\text{return: unspecified}
\end{align*}
\]

If textual-output-port is not supplied, it defaults to the current output port.

pretty-print is similar to write except that it uses any number of spaces and newlines in order to print obj in a style that is pleasing to look at and which shows the nesting level
via indentation. For example,

\[
(\text{pretty-print} \ ' (\text{define factorial (lambda (n) (let fact ((i n) (a 1))
    (if (= i 0) a (fact (- i 1) (* a i))))))
\]

might produce

\[
(\text{define factorial}
  \ (\text{lambda (n)}
    \ (\text{let fact ([i n] [a 1])}
      \ (if (= i 0) a (fact (- i 1) (* a i)))))))
\]

\[
(\text{pretty-file ifn ofn}) \quad \text{procedure}
\]

returns: unspecified
libraries: (chezscheme)

\textit{ifn} and \textit{ofn} must be strings. \texttt{pretty-file} reads each object in turn from the file named by \textit{ifn} and pretty prints the object to the file named by \textit{ofn}. Comments present in the input are discarded by the reader and so do not appear in the output file. If the file named by \textit{ofn} already exists, it is replaced.

\[
(\text{pretty-format sym}) \quad \text{procedure}
\]

returns: see below
\[
(\text{pretty-format sym fmt}) \quad \text{procedure}
\]

returns: unspecified
libraries: (chezscheme)

By default, the pretty printer uses a generic algorithm for printing each form. This procedure is used to override this default and guide the pretty-printers treatment of specific forms. The symbol \textit{sym} names a syntactic form or procedure. With just one argument, \texttt{pretty-format} returns the current format associated with \textit{sym}, or \texttt{#f} if no format is associated with \textit{sym}.

In the two-argument case, the format \textit{fmt} is associated with \textit{sym} for future invocations of the pretty printer. \textit{fmt} must be in the formatting language described below.

\[
\langle \texttt{fmt} \rangle \rightarrow (\texttt{quote symbol})
\]

| \texttt{var}
| \texttt{symbol}
| (\texttt{read-macro string symbol})
| (\texttt{meta})
| (\texttt{bracket . fmt-tail})
| (\texttt{alt fmt fmt*})
| \texttt{fmt-tail}

\[
\texttt{fmt-tail} \rightarrow ()
\]

| (\texttt{tab fmt ...})
| (\texttt{fmt tab ...})
| (\texttt{tab fmt . fmt-tail})
Some of the format forms are used for matching when there are multiple alternatives, while others are used for matching and control indentation or printing. A description of each `fmt` is given below.

- **(quote symbol)**: This matches only the symbol `symbol`.
- **var**: This matches any symbol.
- **symbol**: This matches any input.
- **(read-macro string symbol)**: This is used for read macros like `quote` and `syntax`. It matches any input of the form `(symbol subform)`. For forms that match, the pretty printer prints `string` immediately followed by `subform`.
- **(meta)**: This is a special case used for the `meta` keyword (Section 11.8) which is used as a keyword prefix of another form.
- **(alt fmt fmt*)**: This compares the input against the specified formats and uses the one that is the closest match. Most often, one of the formats will match exactly, but in other cases, as when input is malformed or appears in abstract form in the template of a syntactic abstraction, none of the formats will match exactly.
- **(bracket . fmt-tail)**: This matches any list-structured input and prints the input enclosed in square brackets, i.e., `[ and ]`, rather than parentheses.
- **fmt-tail**: This matches any list-structured input.

Indentation of list-structured forms is determined via the `fmt-tail` specifier used to the last two cases above. A description of each `fmt-tail` is given below.

- **()`**: This matches an empty list tail.
- **(tab fmt ...)**: This matches the tail of any proper list; if the tail is nonempty and the list does not fit entirely on the current line, a line break is inserted before the first subform of the tail and `tab` (see below) determines the amount by which this and all subsequent subforms are indented.
- **(fmt tab ...)**: This matches the tail of any proper list; if the tail is nonempty and the list does not fit entirely on the current line, a line break is inserted after the first subform of the tail and `tab` (see below) determines the amount by which all subsequent subforms are indented.
- **(tab fmt . fmt-tail)**: This matches a nonempty tail if the tail of the tail matches `fmt-tail`. If the list does not fit entirely on the current line, a line break is inserted before the first subform of the tail and `tab` (see below) determines the amount by which the subform is indented.
- **(fmt ...)**: This matches the tail of any proper list and specified that no line breaks are to be inserted before or after the current or subsequent subforms.
(fmt . fmt-tail): This matches a nonempty tail if the tail of the tail matches fmt-tail and specifies that no line break is to be inserted before or after the current subform.

(fill tab fmt ...): This matches the tail of any proper list and invokes a fill mode in which the forms are packed with as many as will fit on each line.

A tab determines the amount by which a list subform is indented. If tab is a nonnegative exact integer int, the subform is indented int spaces in from the character position just after the opening parenthesis or bracket of the parent form. If tab is #f, the standard indentation is used. The standard indentation can be determined or changed via the parameter pretty-standard-indent, which is described later in this section.

In cases where a format is given that doesn’t quite match, the pretty printer tries to use the given format as far as it can. For example, if a format matches a list-structured form with a specific number of subforms, but more or fewer subform are given, the pretty printer will discard or replicate subform formats as necessary.

Here is an example showing the formatting of let might be specified.

```
(pretty-format 'let
  '(alt (let ([bracket var x] 0 ...) #f e #f e ...)
       (let var ([bracket var x] 0 ...) #f e #f e ...)))
```

Since let comes in two forms, named and unnamed, two alternatives are specified. In either case, the bracket fmt is used to enclose the bindings in square brackets, with all bindings after the first appearing just below the first (and just after the enclosing opening parenthesis), if they don’t all fit on one line. Each body form is indented by the standard indentation.

pretty-line-length
pretty-one-line-limit

The value of each of these parameters must be a positive fixnum.

The parameters pretty-line-length and pretty-one-line-limit control the output produced by pretty-print. pretty-line-length determines after which character position (starting from the first) on a line the pretty printer attempts to cut off output. This is a soft limit only; if necessary, the pretty-printer will go beyond pretty-line-length.

pretty-one-line-limit is similar to pretty-line-length, except that it is relative to the first nonblank position on each line of output. It is also a soft limit.

pretty-initial-indent

The value of this parameter must be a nonnegative fixnum.

The parameter pretty-initial-indent is used to tell pretty-print where on an output line it has been called. If pretty-initial-indent is zero (the default), pretty-print assumes that the first line of output it produces will start at the beginning of the line. If
set to a nonzero value \( n \), \texttt{pretty-print} assumes that the first line will appear at character position \( n \) and will adjust its printing of subsequent lines.

\begin{verbatim}
pretty-standard-indent \textbf{thread parameter}
\end{verbatim}

libraries: (chezscheme)

The value of this parameter must be a nonnegative fixnum.

This determines the amount by which \texttt{pretty-print} indents subexpressions of most forms, such as \texttt{let} expressions, from the form’s keyword or first subexpression.

\begin{verbatim}
pretty-maximum-lines \textbf{thread parameter}
\end{verbatim}

libraries: (chezscheme)

The parameter \texttt{pretty-maximum-lines} controls how many lines \texttt{pretty-print} prints when it is called. If set to \#f (the default), no limit is imposed; if set to a nonnegative fixnum \( n \), at most \( n \) lines are printed.

\section*{9.13. Formatted Output}

\begin{verbatim}
(format format-string obj ...)
(format #f format-string obj ...)
(format #t format-string obj ...)
(format textual-output-port format-string obj ...)
\end{verbatim}

\textbf{procedure}

returns: see below

libraries: (chezscheme)

When the first argument to format is a string or \#f (first and second forms above), \texttt{format} constructs an output string from \texttt{format-string} and the objects \texttt{obj} ... . Characters are copied from \texttt{format-string} to the output string from left to right, until \texttt{format-string} is exhausted. The format string may contain one or more format directives, which are multi-character sequences prefixed by a tilde (~). Each directive is replaced by some other text, often involving one or more of the \texttt{obj} ... arguments, as determined by the semantics of the directive.

When the first argument is \#t, output is sent to the current output port instead, as with \texttt{printf}. When the first argument is a port, output is sent to that port, as with \texttt{fprintf}. \texttt{printf} and \texttt{fprintf} are described later in this section.

Chez Scheme’s implementation of \texttt{format} supports all of the Common Lisp \[30\] format directives except for those specific to the Common Lisp pretty printer. Please consult a Common Lisp reference or the Common Lisp Hyperspec for complete documentation. A few of the most useful directives are described below.

Absent any format directives, \texttt{format} simply displays its string argument.

\begin{verbatim}
(format "hi there") ⇒ "hi there"
\end{verbatim}
The ~s directive is replaced by the printed representation of the next obj, which may be any object, in machine-readable format, as with write.

(format "hi ~s" 'mom) ⇒ "hi mom"
(format "hi ~s" "mom") ⇒ "hi \"mom\""
(format "hi -s-s" 'mom #!) ⇒ "hi mom\#\!"

The general form of a ~s directive is actually -mincol, colinc, minpad, padchars, and the s can be preceded by an at sign ( @ ) modifier. These additional parameters are used to control padding in the output, with at least minpad copies of padchar plus an integer multiple of colinc copies of padchar to make the total width, including the written object, mincol characters wide. The padding is placed on the left if the @ modifier is present, otherwise on the right. mincol and minpad default to 0, colinc defaults to 1, and padchar defaults to space. If specified, padchar is prefixed by a single quote mark.

(format "-10s" 'hello) ⇒ "hello   "
(format "-10@s" 'hello) ⇒ "   hello"
(format "-10,,,'*@s" 'hello) ⇒ "*****hello"

The -a directive is similar, but prints the object as with display.

(format "hi -s-s" "mom" #!) ⇒ "hi \"mom\"#\!"
(format "hi -a-a" "mom" #!) ⇒ "hi mom!"

A tilde may be inserted into the output with --, and a newline may be inserted with -% (or embedded in the string with \n).

(format "--line one,-%line two.--") ⇒ "-line one,\nline two.-"
(format "--line one,\nline two.--") ⇒ "-line one,\nline two.-"

Real numbers may be printed in floating-point notation with -f.

(format "-f" 3.14159) ⇒ 3.14159

Exact numbers may printed as well as inexact numbers in this manner; they are simply converted to inexact first as if with exact->inexact.

(format "-f" 1/3) ⇒ "0.3333333333333333"

The general form is actually -w, d, k, overflowchar, padcharf. If specified, w determines the overall width of the output, and d the number of digits to the right of the decimal point. padchar, which defaults to space, is the pad character used if padding is needed. Padding is always inserted on the left. The number is scaled by 10^k when printed; k defaults to zero. The entire w-character field is filled with copies of overflowchar if overflowchar is specified and the number cannot be printed in w characters. k defaults to 1 If an @ modifier is present, a plus sign is printed before the number for nonnegative inputs; otherwise, a sign is printed only if the number is negative.

(format "-3f" 3.14159) ⇒ "3.142"
(format "-10f" 3.14159) ⇒ " 3.14159"
Real numbers may also be printed with \texttt{-e} for scientific notation or with \texttt{-g}, which uses either floating-point or scientific notation based on the size of the input.

\begin{verbatim}
(format "-e" 1e23) ⇒ "1.0e+23"
(format "-g" 1e23) ⇒ "1.0e+23"
\end{verbatim}

A real number may also be printed with \texttt{-$}, which uses monetary notation defaulting to two digits to the right of the decimal point.

\begin{verbatim}
(format "$-\$" (* 39.95 1.06)) ⇒ "$42.35"
(format "-$USD" 1/3) ⇒ "0.33USD"
\end{verbatim}

Words can be pluralized automatically using \texttt{p}.

\begin{verbatim}
(format "-s bear-\:p in -s den-\:p" 10 1) ⇒ "10 bears in 1 den"
\end{verbatim}

Numbers may be printed out in words or roman numerals using variations on \texttt{-r}.

\begin{verbatim}
(format "-r" 2599) ⇒ "two thousand five hundred ninety-nine"
(format "-r" 99) ⇒ "ninety-ninth"
(format ":r" 2599) ⇒ "MMDXCIX"
\end{verbatim}

Case conversions can be performed by bracketing a portion of the format string with the \texttt{-@} and \texttt{-} directives.

\begin{verbatim}
(format "-@(-r-)-" 2599) ⇒ "Two thousand five hundred ninety-nine"
(format "-@:(-a-)" "Ouch!") ⇒ "OUCH!"
\end{verbatim}

Some of the directives shown above have more options and parameters, and there are other directives as well, including directives for conditionals, iteration, indirection, and justification. Again, please consult a Common Lisp reference for complete documentation.

An implementation of a greatly simplified version of \texttt{format} appears in Section 12.6 of \textit{The Scheme Programming Language, 4th Edition}.

\begin{verbatim}
(printf format-string obj ...) procedure
 fprintf textual-output-port format-string obj ...) procedure
\end{verbatim}

These procedures are simple wrappers for \texttt{format}. \texttt{printf} prints the formatted output to the current output, as with a first-argument of \texttt{#t} to \texttt{format}, and \texttt{fprintf} prints the formatted output to the \texttt{textual-output-port}, as when the first argument to \texttt{format} is a port.

The I/O control operations described in this section are used to control how the reader reads and printer writes, displays, or pretty-prints characters, symbols, gensyms, numbers, vectors, long or deeply nested lists or vectors, and graph-structured objects.

(char-name obj)  procedure
returns: see below
(char-name name char)  procedure
returns: unspecified
libraries: (chezscheme)

(char-name) is used to associate names (symbols) with characters or to retrieve the most recently associated name or character for a given character or name. A name can map to only one character, but more than one name can map to the same character. The name most recently associated with a character determines how that character prints, and each name associated with a character may be used after the '#' character prefix to name that character on input.

Character associations created by char-name are ignored by the printer unless the parameter print-char-name is set to a true value. The reader recognizes character names established by char-name except after #!r6rs, which is implied within a library or R6RS top-level program.

In the one-argument form, obj must be a symbol or character. If it is a symbol and a character is associated with the symbol, char-name returns that character. If it is a symbol and no character is associated with the symbol, char-name returns #f. Similarly, if obj is a character, char-name returns the most recently associated symbol for the character or #f if no name is associated with the character. For example, with the default set of character names:

(char-name #\space) ⇒ space
(char-name 'space) ⇒ #\space
(char-name 'nochar) ⇒ #f
(char-name #\a) ⇒ #f

When passed two arguments, name is added to the set of names associated with char, and any other association for name is dropped. char may be #f, in which case any other association for name is dropped and no new association is formed. In either case, any other names associated with char remain associated with char.

The following interactive session demonstrates the use of char-name to establish and remove associations between characters and names, including the association of more than one name with a character.

(print-char-name #t)
(char-name 'etx) ⇒ #f
(char-name 'etx #\x3)
(char-name 'etx) ⇒ #\etx

When passed two arguments, name is added to the set of names associated with char, and any other association for name is dropped. char may be #f, in which case any other association for name is dropped and no new association is formed. In either case, any other names associated with char remain associated with char.

The following interactive session demonstrates the use of char-name to establish and remove associations between characters and names, including the association of more than one name with a character.

When using the expression editor, it is necessary to type Control-J to force the editor to read the erroneous \etx input on the two inputs above that result in read errors, since typing Enter causes the expression editor to read the input only if the input is well-formed.)

The reader does not recognize hex scalar value escapes in character names, as it does in symbols, so \newline is not equivalent to \newline. In general, programmers should avoid the use of character name symbols that cannot be entered without the use of hex scalar value escapes or other symbol-name escape mechanisms, since such character names will not be readable.

---

**print-char-name**

*thread parameter*

*libraries: (chezscheme)*

When **print-char-name** is set to #f (the default), associations created by **char-name** are ignored by write, put-datum, pretty-print, and the format “-s” directive. Otherwise, these procedures use the names established by **char-name** when printing character objects.

---

**case-sensitive**

*thread parameter*

*libraries: (chezscheme)*

The **case-sensitive** parameter determines whether the reader is case-sensitive with respect to symbol and character names. When set to true (the default, as required by the Revised® Report) the case of alphabetic characters within symbol names is significant. When set to #f, case is insignificant. More precisely, when set to #f, symbol and character names are folded (as if by string-foldcase); otherwise, they are left as they appear in the input.

The value of the **case-sensitive** matters only if neither #!fold-case nor #!no-fold-case has appeared previously in the same input stream. That is, symbol and character name are folded if #!fold-case has been seen. They are not folded if #!no-fold-case has been seen. If neither has been seen, they are folded if and only if (case-sensitive) is #f.
(case-sensitive) ⇒ #t
(eq? 'abc 'ABC) ⇒ #f
'ABC ⇒ ABC
(case-sensitive #f)
'ABC ⇒ abc
(eq? 'abc 'ABC) ⇒ #t

print-graph thread parameter
libraries: (chezscheme)

When print-graph is set to a true value, write and pretty-print locate and print objects with shared structure, including cycles, in a notation that may be read subsequently with read. This notation employs the syntax “#n=obj,” where n is a nonnegative integer and obj is the printed representation of an object, to label the first occurrence of obj in the output. The syntax “#n#” is used to refer to the object labeled by n thereafter in the output. print-graph is set to #f by default.

If graph printing is not enabled, the settings of print-length and print-level are insufficient to force finite output, and write or pretty-print detects a cycle in an object it is given to print, a warning is issued (an exception with condition type &warning is raised) and the object is printed as if print-graph were enabled.

Since objects printed through the -s option in the format control strings of format, printf, and fprintf are printed as with write, the printing of such objects is also affected by print-graph.

(parameterize ([print-graph #t])
  (let ([x (list 'a 'b)])
    (format "-s" (list x x))) ⇒ "(#0=(a b) #0#)

(parameterize ([print-graph #t])
  (let ([x (list 'a 'b)])
    (set-car! x x)
    (set-cdr! x x)
    (format "-s" x))) ⇒ "#0=(#0# . #0#)

The graph syntax is understood by the procedure read, allowing graph structures to be printed and read consistently.

print-level thread parameter
print-length thread parameter
libraries: (chezscheme)

These parameters can be used to limit the extent to which nested or multiple-element structures are printed. When called without arguments, print-level returns the current print level and print-length returns the current print length. When called with one argument, which must be a nonnegative fixnum or #f, print-level sets the current print level and print-length sets the current print length to the argument.
When `print-level` is set to a nonnegative integer $n$, `write` and `pretty-print` traverse only $n$ levels deep into nested structures. If a structure being printed exceeds $n$ levels of nesting, the substructure beyond that point is replaced in the output by an ellipsis (\ldots). `print-level` is set to `#f` by default, which places no limit on the number of levels printed.

When `print-length` is set to a nonnegative integer $n$, the procedures `write` and `pretty-print` print only $n$ elements of a list or vector, replacing the remainder of the list or vector with an ellipsis (\ldots). `print-length` is set to `#f` by default, which places no limit on the number of elements printed.

Since objects printed through the `-s` option in the format control strings of `format`, `printf`, and `fprintf` are printed as with `write`, the printing of such objects is also affected by `print-level` and `print-length`.

The parameters `print-level` and `print-length` are useful for controlling the volume of output in contexts where only a small portion of the output is needed to identify the object being printed. They are also useful in situations where circular structures may be printed (see also `print-graph`).

```
(format "-s" '(((a) b) c) d e f g)) ⇒ "(((a) b) c) d e f g)"

(parameterize ([print-level 2])
 (format "-s" '(((a) b) c) d e f g)) ⇒ "(((...) c) d e f g)"

(parameterize ([print-length 3])
 (format "-s" '(((a) b) c) d e f g)) ⇒ "(((a) b) c) d e ..."

(parameterize ([print-level 2]
 [print-length 3])
 (format "-s" '(((a) b) c) d e f g)) ⇒ "(((...) c) d e ..."
```

`print-radix` thread parameter

libraries: (chezscheme)

The `print-radix` parameter determines the radix in which numbers are printed by `write`, `pretty-print`, and `display`. Its value should be an integer between 2 and 36, inclusive. Its default value is 10.

When the value of `print-radix` is not 10, `write` and `pretty-print` print a radix prefix before the number (`#b` for radix 2, `#o` for radix 8, `#x` for radix 16, and `#n` for any other radix $n$).

Since objects printed through the `-s` and `-a` options in the format control strings of `format`, `printf`, and `fprintf` are printed as with `write` and `display`, the printing of such objects is also affected by `print-radix`.

```
(format "-s" 11242957) ⇒ "11242957"

(parameterize ([print-radix 16])
 (format "-s" 11242957)) ⇒ "#xAB8DCD"
```
9. Input/Output Operations

(parameterize ([print-radix 16])
  (format "-a" 11242957))  ⇒  "AB8DCD"

print-gensym  thread parameter
libraries: (chezscheme)

When print-gensym is set to #t (the default) gensyms are printed with an extended symbol syntax that includes both the pretty name and the unique name of the gensym: #{pretty-name unique-name}. When set to pretty, the pretty name only is shown, with the prefix #: When set to pretty/suffix, the printer prints the gensym’s “pretty” name along with a suffix based on the gensym’s “unique” name, separated by a dot ( "." ). If the gensym’s unique name is generated automatically during the current session, the suffix is that portion of the unique name that is not common to all gensyms created during the current session. Otherwise, the suffix is the entire unique name. When set to #f, the pretty name only is shown, with no prefix.

Since objects printed through the ~s option in the format control strings of format, printf, errorf, etc., are printed as with write, the printing of such objects is also affected by print-gensym.

When printing an object that may contain more than one occurrence of a gensym and print-graph is set to pretty or #f, it is useful to set print-graph to #t so that multiple occurrences of the same gensym are marked as identical in the output.

(let ([g (gensym)])
  (format "-s" g))  ⇒  "#{g0 bdids2x16v49vgwe-a}"

(let ([g (gensym)])
  (parameterize ([print-gensym 'pretty])
    (format "-s" g)))  ⇒  "#:g1"

(let ([g (gensym)])
  (parameterize ([print-gensym #f])
    (format "-s" g)))  ⇒  "g2"

(let ([g (gensym)])
  (parameterize ([print-graph #t] [print-gensym 'pretty])
    (format "-s" (list g g)))  ⇒  "(#0=#:g3 #0#)"

(let ([g1 (gensym "x")]
     [g2 (gensym "x")]
     [g3 (gensym "y")])
  (parameterize ([print-gensym 'pretty/suffix])
    (format "-s -s -s" g1 g2 g3)))  ⇒  "x.1 x.2 y.3"

print-brackets  thread parameter
libraries: (chezscheme)

When print-brackets is set to a true value, the pretty printer (see pretty-print) uses
square brackets rather than parentheses around certain subexpressions of common control structures, e.g., around let bindings and cond clauses. print-brackets is set to #t by default.

(let ([p (open-output-string)])
  (pretty-print '(let ([x 3]) x) p) ⇒ "(let ([x 3]) x)
  (get-output-string p))

(parameterize ([print-brackets #f])
  (let ([p (open-output-string)])
    (pretty-print '(let ([x 3]) x) p) ⇒ "(let ((x 3)) x)
    (get-output-string p)))

print-extended-identifiers thread parameter
libraries: (chezscheme)

Chez Scheme extends the syntax of identifiers as described in Section 1.1 except within a set of forms prefixed by #!r6rs (which is implied in a library or top-level program).

When this parameter is set to false (the default), identifiers in the extended set are printed with hex scalar value escapes as necessary to conform to the R6RS syntax for identifiers. When this parameter is set to a true value, identifiers in the extended set are printed without the escapes. Identifiers whose names fall outside of both syntaxes are printed with the escapes regardless of the setting of this parameter.

For example:

(parameterize ([print-extended-identifiers #f])
  (printf "\x2D;-- \x7B; \x2E;xyz\n
\x31;23

while

(parameterize ([print-extended-identifiers #t])
  (printf "\x31;23\n
\x31;23

prints

(\x31;+ \x2D;-- \x7B; \x2E;xyz)
\x31;23
print-vector-length  thread parameter
libraries: (chezscheme)

When print-vector-length is set to a true value, write, put-datum, and pretty-print includes the length for all vectors between the “#” and open parenthesis, all bytevectors between the “#vu8” and open parenthesis, and all fxvectors between the “#vfx” and open parenthesis. This parameter is set to #f by default.

When print-vector-length is set to a true value, write, put-datum, and pretty-print also suppress duplicated trailing elements in the vector to reduce the amount of output. This form is also recognized by the reader.

Since objects printed through the -s option in the format control strings of format, printf, and fprintf are printed as with write, the printing of such objects is also affected by the setting of print-vector-length.

(format "-s" (vector 'a 'b 'c 'c 'c)) ⇒ "#(a b c c c)"

(parameterize ([print-vector-length #t])
  (format "-s" (vector 'a 'b 'c 'c 'c))) ⇒ "#5(a b c)"

(parameterize ([print-vector-length #t])
  (format "-s" (bytevector 1 2 3 4 4 4))) ⇒ "#6vu8(1 2 3 4)"

(parameterize ([print-vector-length #t])
  (format "-s" (fxvector 1 2 3 4 4 4))) ⇒ "#6vfx(1 2 3 4)"

print-precision  thread parameter
libraries: (chezscheme)

When print-precision is set to #f (the default), write, put-datum, pretty-print, and the format “-s” directive do not include the vertical-bar “mantissa-width” syntax after each floating-point number—except for subnormal floating-point numbers, in which case precision printing is controlled by print-subnormal-precision. When set to a nonnegative exact integer, the mantissa width is included, as per the precision argument to number->string.

(format "-s" 1e-100) ⇒ "1e-100"

(parameterize ([print-precision 32])
  (format "-s" 1e-100)) ⇒ "1e-100|53"

(format "-s" 1e-310) ⇒ "1e-310|45"

print-subnormal-precision  thread parameter
libraries: (chezscheme)

When print-subnormal-precision is set to a true value (the default), write, put-datum, pretty-print, and the format “-s” directive include the vertical-bar “mantissa-width” syntax after each floating-point number whose value is subnormal (roughly 4.94e-324 to 2.225e-308), regardless of the value of print-precision. When print-subnormal-precision and
print-precision are both set to #f; precision is not printed for a subnormal value.

\[
\text{(format } "-s" \text{ 1e-310) } \Rightarrow \text{ "1e-310|45"}
\]
\[
\text{(parameterize ([print-subnormal-precision #f])}
\]
\[
\text{(format } "-s" \text{ 1e-310)) } \Rightarrow \text{ "1e-310"}
\]
\[
\text{(parameterize ([print-precision 32]}
\]
\[
\text{[print-subnormal-precision #f])}
\]
\[
\text{(format } "-s" \text{ 1e-310)) } \Rightarrow \text{ "1e-310|45"}
\]

print-positive-exponent-sign thread parameter
libraries: (chezscheme)

When print-positive-exponent-sign is set to a true value, then when a flonum is printed in exponential form and the exponent is positive, a plus sign is written before the exponent. When print-positive-exponent-sign is set #f (the default), no plus sign is written before a positive exponent.

print-select-flonum-exponential-format thread parameter
libraries: (chezscheme)

The value of print-select-flonum-exponential-format must be a procedure that accepts three arguments: a radix as an integer between 2 and 36 (inclusive), an exponent as an integer, and the number of non-zero significant digits in the flonum’s printed form using the matissa (where the first digit is before the “decimal” point). If the procedure returns a true value, a number is printed in exponential form, otherwise it is printed in nonexponential form.

\[
\text{(format } "-s -s" \text{ 1e2 1e8) } \Rightarrow \text{ "100.0 100000000.0"}
\]
\[
\text{(parameterize ([print-select-flonum-exponential-format}
\]
\[
\text{(lambda (radix exponent digits)
\]
\[
\text{ (> exponent 3))))}
\]
\[
\text{(format } "-s -s" \text{ 1e2 1e8)) } \Rightarrow \text{ "100.0 1e8"}
\]
\[
\text{(parameterize ([print-select-flonum-exponential-format}
\]
\[
\text{(lambda (radix exponent digits)
\]
\[
\text{ (< digits 3))))}
\]
\[
\text{(format } "-s -s -s" \text{ 1e2 1.5e8 3.14159e-8)) } \Rightarrow \text{ "1e2 1.5e8 0.0000000314159"}
\]

print-unicode thread parameter
libraries: (chezscheme)

When print-unicode is set to #f, write, put-datum, pretty-print, and the format “-s” directive display Unicode characters with encodings $80_{16}$ (128) and above that appear within character objects, symbols, and strings using hexadecimal character escapes. When set to a true value (the default), they are displayed like other printing characters, as if by put-char.
9.15. Fasl Output

The procedures `write` and `pretty-print` print objects in a human readable format. For objects with external datum representations, the output produced by `write` and `pretty-print` is also machine-readable with `read`. Objects with external datum representations include pairs, symbols, vectors, strings, numbers, characters, booleans, and records but not procedures and ports.

An alternative fast loading, or fasl, format may be used for objects with external datum representations. The fasl format is not human readable, but it is machine readable and both more compact and more quickly processed by `read`. This format is always used for compiled code generated by `compile-file`, but it may also be used for data that needs to be written and read quickly, such as small databases encoded with Scheme data structures.

Objects are printed in fasl format with `fasl-write`. Because the fasl format is a binary format, fasl output must be written to a binary port. For this reason, it is not possible to include data written in fasl format with textual data in the same file, as was the case in earlier versions of Chez Scheme. Similarly, the (textual) reader does not handle objects written in fasl format; the procedure `fasl-read`, which requires a binary input port, must be used instead.

```
(fasl-write obj binary-output-port) ; procedure
(fasl-write obj binary-output-port external-pred) ; procedure
(fasl-write obj binary-output-port external-pred omit-rtds?) ; procedure
```

returns: unspecified
libraries: (chezscheme)

`fasl-write` writes the fasl representation of `obj` to `binary-output-port`. An exception is raised with condition-type `&assertion` if `obj` or any portion of `obj` has no external fasl representation, e.g., if `obj` is or contains a procedure.

If `externals-pred` is provided and not `#f`, then it must be a procedure that accepts one argument. It is applied to each distinct object encountered in `obj`, including symbols, but not necessarily values of other primitive datatypes for which `equal?` implies `eq?`. If `externals-pred` returns true for an object, that object is not written to the fasl representation. Instead, a placeholder is written containing a position as the number of preceding calls to `externals-pred` that had returned true. Typically, for each object where it returns true, `externals-pred` saves the object through its closure. When the fasl representation is read with `fasl-read`, a vector with as many items as generated positions must be provided, and each placeholder is replaced with the corresponding vector element. Beware that replacing values used for system-internal data structures (which are always instances of primitive datatypes) with non-equal values at load time results in undefined behavior.
If `omit-rtds?` is present and true, then any record types relevant to `obj` are not written to the fasl representation. When the fasl representation is read, these record types must already be declared in the loading context, and the loading context is assumed to have compatible record-type registrations using the same unique ID. Behavior if the loading context has an incompatible record-type registration using the same (ostensibly unique) ID is undefined.

The fasl representation of `obj` is compressed if the parameter `fasl-compressed`, described below, is set to `#t`, its default value. For this reason, `binary-output-port` generally should not be opened with the compressed option. A warning is issued (an exception with condition type `&warning` is raised) on the first attempt to write fasl objects to or read fasl objects from a compressed file.

```scheme
(define bop (open-file-output-port "tmp.fsl"))
(fasl-write '(a b c) bop)
(close-port bop)

(define bip (open-file-input-port "tmp.fsl"))
(fasl-read bip) ⇒ (a b c)
(fasl-read bip) ⇒ #!eof
(close-port bip)
```

```scheme
(fasl-read binary-input-port) procedure
(fasl-read binary-input-port situation) procedure
(fasl-read binary-input-port situation externals) procedure
returns: unspecified
libraries: (chezscheme)
```

If present, `situation` must be one of the symbols `load`, `visit`, or `revisit`; it defaults to `load`. If present, `externals` must be a vector; it defaults to `'#()'.

`fasl-read` reads one object from `binary-input-port`, which must be positioned at the front of an object written in fasl format. `fasl-read` returns the eof object if the file is positioned at the end of file. If the situation is `visit`, `fasl-read` skips over any revisit (run-time-only) objects, and if the situation is `revisit`, `fasl-read` skips over any visit (compile-time-only) objects. It doesn’t skip any if the situation is `load`. Similarly, objects marked as both visit and revisit (e.g., object code corresponding to source code within an `eval-when` form with situation `load` or situations `visit` and `revisit`) are never skipped.

The `externals` vector must have the same length as the number of true-returning calls to `external-pred` during the `fasl-write` call that produced the fasl representation.

`fasl-read` automatically decompresses the representation of each fasl object written in compressed format by `fasl-write`. Thus, `binary-input-port` generally should not be opened with the compressed option. A warning is issued (an exception with condition type `&warning` is raised) on the first attempt to write fasl objects to or read fasl objects from a compressed file.
(define bop (open-file-output-port "tmp.fsl"))
(fasl-write ' (a b c) bop)
(close-port bop)

(define bip (open-file-input-port "tmp.fsl"))
(fasl-read bip) ⇒ (a b c)
(fasl-read bip) ⇒ #!eof
(close-port bip)

fasl-compressed thread parameter
libraries: (chezscheme)

When this parameter is set to its default value, #t, fasl-write compresses the representation of each object as it writes it, often resulting in substantially smaller output but possibly taking more time to write and read. The compression format and level are determined by the compress-format and compress-level parameters.

(fasl-file ifn ofn) procedure
returns: unspecified
libraries: (chezscheme)

ifn and ofn must be strings. fasl-file may be used to convert a file in human-readable format into an equivalent file written in fasl format. fasl-file reads each object in turn from the file named by ifn and writes the fasl format for the object onto the file named by ofn. If the file named by ofn already exists, it is replaced.

9.16. File System Interface

This section describes operations on files, directories, and pathnames.

current-directory global parameter
cd global parameter
libraries: (chezscheme)

When invoked without arguments, current-directory returns a string representing the current working directory. Otherwise, the current working directory is changed to the directory specified by the argument, which must be a string representing a valid directory pathname.

cd is bound to the same parameter.

directory-list path procedure
returns: a list of file names
libraries: (chezscheme)

path must be a string. The return value is a list of strings representing the names of files
found in the directory named by path. directory-list raises an exception with condition type &i/o-filename if path does not name a directory or if the process cannot list the directory.

(file-exists? path)
returns: #t if the file named by path exists, #f otherwise
libraries: (chezscheme)

path must be a string. If the optional follow? argument is true (the default), file-exists? follows symbolic links; otherwise it does not. Thus, file-exists? will return #f when handed the pathname of a broken symbolic link unless follow? is provided and is #f.

The Revised\textsuperscript{6} Report file-exists? does not accept the optional follow? argument. Whether it follows symbolic links is unspecified.

(file-regular? path)
returns: #t if the file named by path is a regular file, #f otherwise
libraries: (chezscheme)

path must be a string. If the optional follow? argument is true (the default), file-regular? follows symbolic links; otherwise it does not.

(file-directory? path)
returns: #t if the file named by path is a directory, #f otherwise
libraries: (chezscheme)

path must be a string. If the optional follow? argument is true (the default), this procedure follows symbolic links; otherwise it does not.

(file-symbolic-link? path)
returns: #t if the file named by path is a symbolic link, #f otherwise
libraries: (chezscheme)

path must be a string. file-symbolic-link? never follows symbolic links in making its determination.
9. Input/Output Operations

(file-access-time path/port) procedure
(file-access-time path/port follow?) procedure
returns: the access time of the specified file

(file-change-time path/port) procedure
(file-change-time path/port follow?) procedure
returns: the change time of the specified file

(file-modification-time path/port) procedure
(file-modification-time path/port follow?) procedure
returns: the modification time of the specified file

libraries: (chezscheme)

path/port must be a string or port. If path/port is a string, the time returned is for the file named by the string, and the optional follow? argument determines whether symbolic links are followed. If follow? is true (the default), this procedure follows symbolic links; otherwise it does not. If path/port is a port, it must be a file port, and the time returned is for the associated file. In this case, follow? is ignored.

The returned times are represented as time objects (Section 12.10).

(mkdir path) procedure
(mkdir path mode) procedure
returns: unspecified
libraries: (chezscheme)

path must be a string. mode must be a fixnum.

mkdir creates a directory with the name given by path. All path path components leading up to the last must already exist. If the optional mode argument is present, it overrides the default permissions for the new directory. Under Windows, the mode argument is ignored.

mkdir raises an exception with condition type &i/o-filename if the directory cannot be created.

(delete-file path) procedure
(delete-file path error?) procedure
returns: see below
libraries: (chezscheme)

path must be a string. delete-file removes the file named by path. If the optional error? argument is #f (the default), delete-file returns a boolean value: #t if the operation is successful and #f if it is not. Otherwise, delete-file returns an unspecified value if the operation is successful and raises an exception with condition type &i/o-filename if it is not.

The Revised6 Report delete-file does not accept the optional error? argument but behaves as if error? is true.
9.16. File System Interface

**(delete-directory path)**  
**procedure**

**returns:** see below  
**libraries:** (chezscheme)

*path* must be a string. `delete-directory` removes the directory named by *path*. If the optional `error?` argument is `#f` (the default), `delete-directory` returns a boolean value: `#t` if the operation is successful and `#f` if it is not. Otherwise, `delete-directory` returns an unspecified value if the operation is successful and raises an exception with condition type `&i/o-filename` if it is not. The behavior is unspecified if the directory is not empty, but on most systems the operations will not succeed.

**rename-file old-pathname new-pathname**  
**procedure**

**returns:** unspecified  
**libraries:** (chezscheme)

*old-pathname* and *new-pathname* must be strings. `rename-file` changes the name of the file named by *old-pathname* to *new-pathname*. If the file does not exist or cannot be renamed, an exception is raised with condition type `&i/o-filename`.

**chmod path mode**  
**procedure**

**returns:** unspecified  
**libraries:** (chezscheme)

*path* must be a string. *mode* must be a fixnum. `chmod` sets the permissions on the file named by *path* to *mode*. Bits 0, 1, and 2 of *mode* are the execute, write, and read permission bits for users other than the file’s owner who are not in the file’s group. Bits 3-5 are the execute, write, and read permission bits for users other than the file’s owner but in the file’s group. Bits 6-8 are the execute, write, and read permission bits for the file’s owner. Bits 7-9 are the Unix sticky, set-group-id, and set-user-id bits. Under Windows, all but the user “write” bit are ignored. If the file does not exist or the permissions cannot be changed, an exception is raised with condition type `&i/o-filename`.

**get-mode path**  
**procedure**

**returns:** the current permissions mode for *path*  
**libraries:** (chezscheme)

*path* must be a string. `get-mode` retrieves the permissions on the file named by *path* and returns them as a fixnum in the same form as the *mode* argument to `chmod`. If the optional `follow?` argument is true (the default), this procedure follows symbolic links; otherwise it does not.
9. Input/Output Operations

(directory-separator? char)

procedure

returns: #t if char is a directory separator, #f otherwise

libraries: (chezscheme)

The character #\ is a directory separator on all current machine types, and #\ is a directory separator under Windows.

(directory-separator)

procedure

returns: the preferred directory separator

libraries: (chezscheme)

The preferred directory separator is #\ for Windows and #\ for other systems.

(path-build dir-path path)

procedure

returns: a combined path

libraries: (chezscheme)

Combines dir-path and path, adding a directory separator between them if needed.

(path-first path)

(path-rest path)

(path-last path)

(path-parent path)

(path-extension path)

(path-root path)

procedure

returns: the specified component of path

(path-absolute? path)

procedure

returns: #t if path is absolute, otherwise #f

libraries: (chezscheme)

path must be a string. The return value is also a (possibly empty) string.

The path first component is the first directory in the path, or the empty string if the path consists only of a single filename. The path rest component is the portion of the path that does not include the path first component or the directory separator (if any) that separates it from the rest of the path. The path last component is the last (filename) portion of path. The path parent component is the portion of path that does not include the path last component, if any, or the directory separator that separates it from the rest of the path.

If the first component of the path names a root directory (including drives and shares under Windows), home directory (e.g., ~/abc or ~user/abc), the current directory (.), or the parent directory (..), path-first returns that component. For paths that consist only of such a directory, both path-first and path-parent act as identity procedures, while path-rest and path-last return the empty string.

The path extension component is the portion of path that follows the last dot (period) in the last component of a path name. The path root component is the portion of path that does not include the extension, if any, or the dot that precedes it.
9.16. File System Interface

293

If the first component names a root directory (including drives and shares under Windows)
or home directory, path-absolute? returns #t. Otherwise, path-absolute? returns #f.
The tables below identify the components for several example paths, with underscores
representing empty strings.
path
a
a/
a/b
a/b.c
/
/a/b.c
~/a/b.c
~u/a/b.c
../..

abs
#f
#f
#f
#f
#t
#t
#t
#t
#f

first rest
a
_
b
b.c
_
a/b.c
a/b.c
a/b.c
..

_
a
a
a
/
/
~
~u
..

parent last
a
_
b
b.c
_
b.c
b.c
b.c
..

_
a
a
a
/
/a
~/a
~u/a
..

root
a
a/
a/b
a/b
/
/a/b
~/a/b
~u/a/b
../..

ext
_
_
_
c
_
c
c
c
_

The second table shows the components when Windows drives and shares are involved.
path
c:
c:/
c:a/b
//s/a/b.c
//s.com

abs
#f
#t
#f
#t
#t

first
c:
c:/
c:
//s
//s.com

rest
_
_
a/b
a/b.c
_

parent
c:
c:/
c:a
//s/a
//s.com

last root
c:
c:/
c:a/b
//s/a/b
//s.com

_
_
b
b.c
_

ext
_
_
_
c
_

The following procedure can be used to reproduce the tables above.
(define print-table
(lambda path*
(define print-row
(lambda (abs? path first rest parent last root extension)
(printf "~a~11t~a~17t~a~28t~a~39t~a~50t~a~61t~a~73t~a\n"
abs? path first rest parent last root extension)))
(print-row "path" "abs" "first" "rest" "parent" "last" "root" "ext")
(for-each
(lambda (path)
(define uscore (lambda (s) (if (eqv? s "") "_" s)))
(apply print-row path
(map (lambda (s) (if (eqv? s "") "_" s))
(list (path-absolute? path) (path-first path)
(path-rest path) (path-parent path) (path-last path)
(path-root path) (path-extension path)))))
path*)))

For example, the first table can be produced with:
(print-table "a" "a/" "a/b" "a/b.c" "/" "/a/b.c" "~/a/b.c"
"~u/a/b.c" "../..")

while the second can be produced (under Windows) with:


(print-table "c:" "c:" "c:a/b" "/s/a/b.c" "//s.com")

9.17. Generic Port Examples

This section presents the definitions for three types of generic ports: two-way ports, transcript ports, and process ports.

**Two-way ports.** The first example defines `make-two-way-port`, which constructs a textual input/output port from a given pair of textual input and output ports. For example:

```scheme
(define ip (open-input-string "this is the input"))
(define op (open-output-string))
(define p (make-two-way-port ip op))
```

The port returned by `make-two-way-port` is both an input and an output port, and it is also a textual port:

```scheme
(port? p) ⇒ #t
(input-port? p) ⇒ #t
(output-port? p) ⇒ #t
(textual-port? p) ⇒ #t
```

Items read from a two-way port come from the constituent input port, and items written to a two-way port go to the constituent output port:

```scheme
(read p) ⇒ this
(write 'hello p)
(get-output-string op) ⇒ hello
```

The definition of `make-two-way-port` is straightforward. To keep the example simple, no local buffering is performed, although it would be more efficient to do so.

```scheme
(define make-two-way-port
  (lambda (ip op)
    (define handler
      (lambda (msg . args)
        (record-case (cons msg args)
          [block-read (p s n) (block-read ip s n)]
          [block-write (p s n) (block-write op s n)]
          [char-ready? (p) (char-ready? ip)]
          [clear-input-port (p) (clear-input-port ip)]
          [clear-output-port (p) (clear-output-port op)]
          [close-port (p) (mark-port-closed! p)]
          [flush-output-port (p) (flush-output-port op)]
          [file-position (p . pos) (apply file-position ip pos)]
          [file-length (p) (file-length ip)]
          [peek-char (p) (peek-char ip)]
          [port-name (p) "two-way"]
          [read-char (p) (read-char ip)]
        ))
      )
    ))
```
[unread-char (c p) (unread-char c ip)]
[write-char (c p) (write-char c op)]
[else (assertion-violationf 'two-way-port
  "operation ~s not handled"
  msg)))]
(make-input/output-port handler "" "")

Most of the messages are passed directly to one of the constituent ports. Exceptions are close-port, which is handled directly by marking the port closed, port-name, which is also handled directly. file-position and file-length are rather arbitrarily passed off to the input port.

Transcript ports. The next example defines make-transcript-port, which constructs a textual input/output port from three ports: a textual input port ip and two textual output ports, op and tp. Input read from a transcript port comes from ip, and output written to a transcript port goes to op. In this manner, transcript ports are similar to two-way ports. Unlike two-way ports, input from ip and output to op is also written to tp, so that tp reflects both input from ip and output to op.

Transcript ports may be used to define the Scheme procedures transcript-on and transcript-off, or the Chez Scheme procedure transcript-cafe. For example, here is a definition of transcript-cafe:

(define transcript-cafe
  (lambda (pathname)  
    (let ([tp (open-output-file pathname 'replace)])  
      (let ([p (make-transcript-port  
                 (console-input-port)  
                 (console-output-port)  
                 tp)])  
        ; set both console and current ports so that  
        ; the waiter and read/write will be in sync  
        (parameterize ([console-input-port p]  
                       [console-output-port p]  
                       [current-input-port p]  
                       [current-output-port p])  
          (let-values ([vals (new-cafe)])  
            (close-port p)  
            (close-port tp)  
            (apply values vals))))))

The implementation of transcript ports is significantly more complex than the implementation of two-way ports defined above, primarily because it buffers input and output locally. Local buffering is needed to allow the transcript file to reflect accurately the actual input and output performed in the presence of unread-char, clear-output-port, and clear-input-port. Here is the code:

(define make-transcript-port  
  (lambda (ip op tp)  
    (define (handler msg . args)  
      (make-input/output-port handler "" ""))  
    [unread-char (c p) (unread-char c ip)]  
    [write-char (c p) (write-char c op)]  
    [else (assertion-violationf 'two-way-port  
        "operation ~s not handled"
        msg)))]  
    (make-input/output-port handler "" "")))

Transcript ports.
(record-case (cons msg args)
  [block-read (p str cnt)
    (with-interrupts-disabled
      (let ([b (port-input-buffer p)]
            [i (port-input-index p)]
            [s (port-input-size p)])
        (if (< i s)
            (let ([cnt (fxmin cnt (fx- s i))])
              (do ([i i (fx+ i 1)]
                  [j 0 (fx+ j 1)])
                ((fx= j cnt)
                 (set-port-input-index! p i)
                 cnt)
                (string-set! str j (string-ref b i))))
            (let ([cnt (block-read ip str cnt)])
              (unless (eof-object? cnt)
                (block-write tp str cnt))
              cnt)))])
  [char-ready? (p)
    (or (< (port-input-index p) (port-input-size p))
        (char-ready? ip))])
  [clear-input-port (p)
    ; set size to zero rather than index to size
    ; in order to invalidate unread-char
    (set-port-input-size! p 0)]
  [clear-output-port (p)
   (set-port-output-index! p 0)]
  [close-port (p)
    (with-interrupts-disabled
      (flush-output-port p)
      (set-port-output-size! p 0)
      (set-port-input-size! p 0)
      (mark-port-closed! p))]
  [file-position (p . pos)
    (if (null? pos)
        (most-negative-fixnum)
        (assertion-violationf 'transcript-port "cannot reposition"))]
  [flush-output-port (p)
    (with-interrupts-disabled
      (let ([b (port-output-buffer p)]
            [i (port-output-index p)])
          (unless (fx= i 0)
            (block-write op b i)
            (block-write tp b i)
            (set-port-output-index! p 0)
            (set-port-bol! p
             (char=? (string-ref b (fx- i 1)) #\newline)))))
          (flush-output-port op)
          (flush-output-port tp))])
  [peek-char (p)
(with-interrupts-disabled
  (let ([b (port-input-buffer p)]
       [i (port-input-index p)]
       [s (port-input-size p)])
    (if (fx< i s)
        (string-ref b i)
        (begin
          (flush-output-port p)
          (let ([s (block-read ip b)])
            (if (eof-object? s)
                s
                (begin
                  (block-write tp b s)
                  (set-port-input-size! p s)
                  (string-ref b 0))))))))
[port-name (p) "transcript"]
[constituent-ports (p) (values ip op tp)]
[read-char (p) (with-interrupts-disabled
  (let ([c (peek-char p)])
    (unless (eof-object? c)
      (set-port-input-index! p
        (fx+ (port-input-index p) 1)))
    c))]
[unread-char (c p) (with-interrupts-disabled
  (let ([b (port-input-buffer p)]
       [i (port-input-index p)]
       [s (port-input-size p)])
    (when (fx= i 0)
      (assertion-violationf 'unread-char
        "tried to unread too far on ~s" p))
    (set-port-input-index! p (fx- i 1))
    ; following could be skipped; it’s supposed
    ; to be the same character anyway
    (string-set! b (fx- i 1) c)))]
[write-char (c p) (with-interrupts-disabled
  (let ([b (port-output-buffer p)]
       [i (port-output-index p)]
       [s (port-output-size p)])
    (string-set! b i c)
    ; could check here to be sure that we really
    ; need to flush; we may end up here even if
    ; the buffer isn’t full
    (block-write op b (fx+ i 1))
    (block-write tp b (fx+ i 1))
    (set-port-output-index! p 0)
    (set-port-bol! p (char=? c #\newline))))]}
9. Input/Output Operations

[block-write (p str cnt)
 (with-interrupts-disabled
; flush buffered data
 (let ([b (port-output-buffer p)]
     [i (port-output-index p)])
   (unless (fx= i 0)
     (block-write op b i)
     (block-write tp b i)
     (set-port-output-index! p 0)
     (set-port-bol! p (char=? (string-ref b (fx- i 1)) #\newline)))))
; write new data
 (unless (fx= cnt 0)
     (block-write op str cnt)
     (block-write tp str cnt)
     (set-port-bol! p
      (char=? (string-ref str (fx- cnt 1)) #\newline)))
[else (assertion-violationf 'transcript-port
 "operation ~s not handled" msg)])
)
]
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
)
subprocesses via normal Scheme input/output operations.

A process port is created with open-process, which accepts a shell command as a string. open-process sets up a socket, forks a child process, sets up two-way communication via the socket, and invokes the command in a subprocess.

The sample session below demonstrates the use of open-process, running and communicating with another Scheme process started with the “-q” switch to suppress the greeting and prompts.

```scheme
> (define p (open-process "exec scheme -q"))
> (define s (make-string 1000 #\nul))
> (pretty-print '(+ 3 4) p)
> (read p)
7
> (pretty-print '(define (f x) (if (= x 0) 1 (* x (f (- x 1))))) p)
> (pretty-print '(f 10) p)
> (read p)
3628800
> (pretty-print '(exit) p)
> (read p)
#!eof
> (close-port p)
```

Since process ports, like transcript ports, are two-way, the implementation is somewhat similar. The main difference is that a transcript port reads from and writes to its subordinate ports, whereas a process port reads from and writes to a socket. When a process port is opened, the socket is created and subprocess invoked, and when the port is closed, the socket is closed and the subprocess is terminated.

```scheme
(define open-process
  (lambda (command)
    (define handler
      (lambda (pid socket)
        (define (flush-output who p)
          (let ([i (port-output-index p)])
            (when (fx> i 0)
              (check who (c-write socket (port-output-buffer p) i))
              (set-port-output-index! p 0)))))
      (lambda (msg . args)
        (record-case (cons msg args)
          [block-read (p str cnt)
            (with-interrupts-disabled
              (let ([b (port-input-buffer p)]
                    [i (port-input-index p)]
                    [s (port-input-size p)])
                (if (< i s)
                  (let ([cnt (fxmin cnt (fx- s i))])
                    (do ([i i (fx+ i 1)]
                          [j 0 (fx+ j 1)])
                      ((fx= j cnt)
                        ...]))
            ...)))))))
    ...))
)```
(set-port-input-index! p i)
cnt)
(string-set! str j (string-ref b i)))

(begin
  (flush-output 'block-read p)
  (let ([n (check 'block-read
              (c-read socket str cnt))])
    (if (fx= n 0)
      #!eof
      n))))])

[char-ready? (p)
  (or (< (port-input-index p) (port-input-size p))
      (bytes-ready? socket))]

[clear-input-port (p)
 ; set size to zero rather than index to size
 ; in order to invalidate unread-char
 (set-port-input-size! p 0)]

[clear-output-port (p) (set-port-output-index! p 0)]

[close-port (p)
 (with-interrupts-disabled
   (flush-output 'close-port p)
   (set-port-output-size! p 0)
   (set-port-input-size! p 0)
   (mark-port-closed! p)
   (terminate-process pid))]

[file-length (p) 0]

[file-position (p . pos)
  (if (null? pos)
    (most-negative-fixnum)
    (assertion-violationf 'process-port "cannot reposition"))]

[flush-output-port (p)
 (with-interrupts-disabled
   (flush-output 'flush-output-port p))]

[peek-char (p)
 (with-interrupts-disabled
   (let ([b (port-input-buffer p)]
         [i (port-input-index p)]
         [s (port-input-size p)])
     (if (fx< i s)
       (string-ref b i)
       (begin
         (flush-output 'peek-char p)
         (let ([s (check 'peek-char
               (c-read socket b (string-length b)))]
             (if (fx= s 0)
               #!eof
               (begin (set-port-input-size! p s)
                       (string-ref b 0)))))))))

[port-name (p) "process"]

[read-char (p)
(with-interrupts-disabled
  (let ([b (port-input-buffer p)]
        [i (port-input-index p)]
        [s (port-input-size p)])
    (if (fx< i s)
        (begin
          (set-port-input-index! p (fx+ i 1))
          (string-ref b i))
        (begin
          (flush-output 'peek-char p)
          (let ([s (check 'read-char
                           (c-read socket b (string-length b)))]
                (if (fx= s 0)
                    #!eof
                    (begin (set-port-input-size! p s)
                           (set-port-input-index! p 1)
                           (string-ref b 0))))))))

[unread-char (c p)
  (with-interrupts-disabled
    (let ([b (port-input-buffer p)]
          [i (port-input-index p)]
          [s (port-input-size p)])
      (when (fx= i 0)
        (assertion-violationf 'unread-char
                             "tried to unread too far on ~s"
                             p))
      (set-port-input-index! p (fx- i 1))
      ; following could be skipped; supposed to be
      ; same character
      (string-set! b (fx- i 1) c)))]

[write-char (c p)
  (with-interrupts-disabled
    (let ([b (port-output-buffer p)]
          [i (port-output-index p)]
          [s (port-output-size p)])
      (string-set! b i c)
      (check 'write-char (c-write socket b (fx+ i 1)))
      (set-port-output-index! p 0)))]

[block-write (p str cnt)
  (with-interrupts-disabled
    ; flush buffered data
    (flush-output 'block-write p)
    ; write new data
    (check 'block-write (c-write socket str cnt)))]

[else
  (assertion-violationf 'process-port
                        "operation ~s not handled"
                        msg)))]

(let* ([server-socket-name (tmpnam 0)]
        [server-socket (setup-server-socket server-socket-name)])
(dofork
  (lambda () ; child
    (check 'close (close server-socket))
    (let ([sock (setup-client-socket server-socket-name)])
      (dodup 0 sock)
      (dodup 1 sock))
    (check 'execl (execl4 "/bin/sh" "/bin/sh" "-c" command))
    (assertion-violationf 'open-process "subprocess exec failed")
  )
  (lambda (pid) ; parent
    (let ([sock (accept-socket server-socket)])
      (check 'close (close server-socket))
      (let ([ib (make-string 1024)] [ob (make-string 1024)])
        (let ([p (make-input/output-port
                  (handler pid sock)
                  ib ob)])
          (set-port-input-size! p 0)
          (set-port-output-size! p (fx- (string-length ob) 1))
          p))))))))
10. Libraries and Top-level Programs

The Revised\textsuperscript{6} Report describes two units of portable code: libraries and top-level programs. A library is a named collection of bindings with a declared set of explicitly exported bindings, a declared set of imported libraries, and a body that initializes its bindings. A top-level program is a stand-alone program with a declared set of imported libraries and a body that is run when the top-level program is run. The bindings in a library are created and its initialization code run only if the library is used, directly or indirectly, by a top-level program.

The \texttt{import} declarations appearing within libraries and top-level programs serve two purposes: first, they cause the imported libraries to be loaded, and second, they cause the bindings of the imported libraries to become visible in the importing library or top-level program. Libraries are typically stored in the file system, with one library per file, and the library name typically identifies the file-system path to the library, possibly relative to a default or programmer-specified set of library locations. The exact mechanism by which top-level programs are run and libraries are loaded is implementation-dependent.

This chapter describes the mechanisms by which libraries and programs are loaded in Chez Scheme along with various features for controlling and tracking this process. It also describes the set of built-in libraries and syntactic forms for defining new libraries and top-level programs outside of a library or top-level program file.

10.1. Built-in Libraries

In addition to the RNRS libraries mandated by the Revised\textsuperscript{6} Report:

\begin{verbatim}
(rnrs base (6))
(rnrs arithmetic bitwise (6))
(rnrs arithmetic fixnums (6))
(rnrs arithmetic flonums (6))
(rnrs bytevectors (6))
(rnrs conditions (6))
(rnrs control (6))
(rnrs enums (6))
(rnrs eval (6))
(rnrs exceptions (6))
(rnrs files (6))
(rnrs hashtables (6))
\end{verbatim}
10. Libraries and Top-level Programs

The following libraries are provided by Chez Scheme:

- (rnrs io ports (6))
- (rnrs io simple (6))
- (rnrs lists (6))
- (rnrs mutable-pairs (6))
- (rnrs mutable-strings (6))
- (rnrs programs (6))
- (rnrs r5rs (6))
- (rnrs records procedural (6))
- (rnrs records syntactic (6))
- (rnrs records inspection (6))
- (rnrs sorting (6))
- (rnrs syntax-case (6))
- (rnrs unicode (6))

Chez Scheme also provides two additional libraries: (chezscheme) and (chezscheme csv7). The former can also be referenced as (scheme) and the latter can also be referenced as (scheme csv7).

The (chezscheme) library exports bindings for every identifier whose binding is described in this document, including those for keywords like lambda, auxiliary keywords like else, module names like scheme, and procedure names like cons. In most cases where an identifier exported from the (chezscheme) library corresponds to an identifier exported from one of the RNRS libraries, the bindings are identical. In some cases, however, the (chezscheme) bindings extend the rnrs bindings in some way. For example, the (chezscheme) syntax-rules form allows its clauses to have fenders (Section 11.2), while the (rnrs) syntax-rules form does not. Similarly, the (chezscheme) current-input-port procedure accepts an optional port argument that, when specified, sets the current input port to port (Section 9.8), while the (rnrs) current-input-port procedure does not. When the (chezscheme) library extends an RNRS binding in some way, the (chezscheme) library also exports the RNRS version, with the name prefixed by r6rs:, e.g., r6rs:syntax-rules or r6rs:current-input-port.

The (chezscheme csv7) Version 7 backward compatibility library contains bindings for a set of syntactic forms and procedures whose syntax or semantics directly conflicts with the RNRS bindings for the same identifiers. The following identifiers are exported from (chezscheme csv7).

record-field-accessible?
record-field-accessor
record-field-mutable?
record-field-mutator
record-type-descriptor
record-type-field-decls
record-type-field-names
record-type-name
record-type-symbol

The bindings of this library should be used only for old code; new code should use the RNRS variants. Each of these is also available in the (chezscheme) library with the prefix csv7:, e.g., csv7:record-type-name.
The interaction environment in which code outside of a library or RNRS top-level program is scoped contains all of the bindings of the (chezscheme) library, as described in Section 2.3.

10.2. Running Top-level Programs

A top-level program must reside in its own file, which may have any name and may reside anywhere in the file system. A top-level program residing in a file is run by one of three mechanisms: the scheme-script command, the --program command-line argument, or the load-program procedure.

The scheme-script command is used as follows:

```
scheme-script program-filename arg ...
```

It may also be run implicitly on Unix-based systems by placing the line

```
#! /usr/bin/env scheme-script
```

at the front of the file containing the top-level program, making the top-level program file executable, and executing the file. This line may be replaced with

```
#! /usr/bin/scheme-script
```

with /usr/bin replaced by the absolute path to the directory containing scheme-script if it is not in /usr/bin. The first form is recommended in the nonnormative appendices to the Revised 6 Report [29], and works wherever scheme-script appears in the path.

The --program command is used similarly with the scheme or petite executables, either by running:

```
scheme --program program-filename arg ...
petite --program program-filename arg ...
```

or by including

```
#! /usr/bin/scheme --script
```

or

```
#! /usr/bin/petite --script
```

at the front of the top-level program file, making the file executable, and executing the file. Again, /usr/bin should be replaced with the absolute path to the actual directory in which scheme and/or petite resides, if not /usr/bin.

The load-program procedure, described in Section 12.4, is used like load:

```
(load-program string)
```

where string names the file in which the top-level program resides.
Regardless of the mechanism used, if the opening line is in one of the forms described above, or more generally, consists of `#!` followed by a space or a forward slash, the opening line is not considered part of the program and is ignored once the Scheme system starts up and begins to run the program. Thus, the line may be present even in a file loaded by `load-program`. In fact, `load-program` is ultimately used by the other two mechanisms described above, via the value of the `scheme-program` parameter described in Section 12.8, and it is `load-program` that scans past the `#!` line, if present, before evaluating the program.

A top-level program may be compiled with the `compile-program` procedure described in Section 12.4. `compile-program` copies the `#!` line from the source file to the object file, followed by a compiled version of the source code. Any libraries upon which the top-level program depends, other than built-in libraries, must be compiled first via `compile-file` or `compile-library`. This can be done manually or by setting the parameter `compile-imported-libraries` to `#t` before compiling the program. The program must be recompiled if any of the libraries upon which it depends are recompiled. A compiled top-level program can be run just like a source top-level program via each of the mechanisms described above.

In Chez Scheme, a library may also be defined in the REPL or placed in a file to be loaded via `load` or `load-library`. The syntax for a library is the same whether the library is placed in its own file and implicitly loaded via `import`, entered into the REPL, or placed in a file along with other top-level expressions to be evaluated by `load`. A top-level program may also be defined in the REPL or placed in a file to be loaded via `load`, but in this case, the syntax is slightly different. In the language of the Revised\textsuperscript{6} Report, a top-level program is merely an unwrapped sequence of subforms consisting of an `import` form and a body, delimited only by the boundaries of the file in which it resides. In order for a top-level program to be entered in the REPL or placed in a file to be evaluated by `load`, Chez Scheme allows top-level programs to be enclosed in a `top-level-program` form.

### 10.3. Library and Top-level Program Forms

```
(library name exports imports library-body)  syntax
returns: unspecified
libraries: (chezscheme)
```

The `library` form defines a new library with the specified name, exports, imports, and body. Details on the syntax and semantics of the library form are given in Section 10.3 of *The Scheme Programming Language, 4th Edition* and in the Revised\textsuperscript{6} Report.

Only one version of a library can be loaded at any given time, and an exception is raised if a library is implicitly loaded via `import` when another version of the library has already been loaded. Chez Scheme permits a different version of the library, or a new instance of the same version, to be entered explicitly into the REPL or loaded explicitly from a file, to facilitate interactive testing and debugging. The programmer should take care to make sure that any code that uses the library is also reentered or reloaded, to make sure that code accesses the bindings of the new instance of the library.
(library (test (1)) (export x) (import (rnrs)) (define x 3))
(imports)
(define f (lambda () x))
(f) ⇒ 3

(library (test (1)) (export x) (import (rnrs)) (define x 4))
(imports)
(define f (lambda () x))
(f) ⇒ 3 ; oops---forgot to redefine f
(define f (lambda () x))
(f) ⇒ 4

(library (test (2)) (export x) (import (rnrs)) (define x 5))
(imports)
(define f (lambda () x))
(f) ⇒ 5

As with module imports (Section 11.5), a library import may appear anywhere a definition may appear, including at top level in the REPL, in a file to be loaded by load, or within a lambda, let, letrec, letrec*, etc., body. The same import form may be used to import from both libraries and modules.

(library (foo) (export a) (import (rnrs)) (define a 'a-from-foo))
(module bar (b) (define b 'b-from-bar))
(let () (import (foo) bar) (list a b)) ⇒ (a-from-foo b-from-bar)

The import keyword is not visible within a library body unless the library imports it from the (chezscheme) library.

(top-level-program imports body) syntax
returns: unspecified
libraries: (chezscheme)

A top-level-program form may be entered into the REPL or placed in a file to be loaded via load, where it behaves as if its subforms were placed in a file and loaded via load-program. Details on the syntax and semantics of a top-level program are given in Section 10.3 of The Scheme Programming Language, 4th Edition and in the Revised6 Report.

The following transcript illustrates a top-level-program being tested in the REPL.

> (top-level-program (import (rnrs))
   (display "hello!\n"))
hello!

10.4. Standalone import and export forms

Although not required by the Revised6 Report, Chez Scheme supports the use of standalone import and export forms. The import forms can appear anywhere other definitions can appear, including within a library body, module (Section 11.5) body, lambda or other local
body, and at top level. The export forms can appear within the definitions of a library or module body to specify additional exports for the library or module.

Within a library or top-level program, the keywords for these forms must be imported from the (chezscheme) library to be available for use, since they are not defined in any of the Revised6 Report libraries.

An import or import-only form is a definition and can appear anywhere other definitions can appear, including at the top level of a program, nested within the bodies of lambda expressions, and nested within modules and libraries.

Each import-spec must take one of the following forms.

import-set
(for import-set import-level ...)

The for wrapper and import-level are described in Chapter 10 of The Scheme Programming Language, 4th Edition. They are ignored by Chez Scheme, which determines automatically the levels at which identifiers must be imported, as permitted by the Revised6 Report. This frees the programmer from the obligation to do so and results in more generality as well as more precision in the set of libraries actually imported at compile and run time [21, 19].

An import-set must take one of the following forms:

library-spec
module-name
(only import-set identifier ...)  
(except import-set identifier ...) 
(prefix import-set prefix) 
(add-prefix import-set prefix) 
(drop-prefix import-set prefix) 
(rename import-set (import-name internal-name) ...) 
(alias import-set (import-name internal-name) ...)

Several of these are specified by the Revised6 Report; the remainder are Chez Scheme extensions, including module-name and the add-prefix, drop-prefix, and alias forms.

An import or import-only form makes the specified bindings visible in the scope in which they appear. Except at top level, they differ in that import leaves all bindings except for those shadowed by the imported names visible, whereas import-only hides all existing bindings, i.e., makes only the imported names visible. At top level, import-only behaves like import.

Each import-set identifies a set of names to make visible as follows.

library-spec: all exports of the library identified by the Revised6 Report library-spec (Chapter 10).
module-name: all exports of module named by the identifier module-name
(only import-set identifier ...): of those specified by import-set, just identifier ...
(except import-set identifier ...): all specified by import-set except identifier ...
(prefix import-set prefix): all specified by import-set, each prefixed by prefix
(add-prefix import-set prefix): all specified by import-set, each prefixed by prefix (just like prefix)
(drop-prefix import-set prefix): all specified by import-set, with prefix prefix removed
(rename import-set (import-name internal-name) ...): all specified by import-set, with each identifier import-name renamed to the corresponding identifier internal-name
(alias import-set (import-name internal-name) ...): all specified by import-set, with each internal-name as an alias for import-name

The alias form differs from the rename form in that both import-name and internal-name are in the resulting set, rather than just internal-name.

It is a syntax violation if the given selection or transformation cannot be made because of a missing export or prefix.

An identifier made visible via an import of a module or library is scoped as if its definition appears where the import occurs. The following example illustrates these scoping rules, using a local module m.

(library (A) (export x) (import (rnrs)) (define x 0))
(let ([x 1])
  (module m (x setter)
    (define-syntax x (identifier-syntax z))
    (define setter (lambda (x) (set! z x)))
    (define z 2))
  (let ([y x] [z 3])
    (import m (prefix (A) a:))
    (setter 4)
    (list x a:x y z))) ⇒ (4 0 1 3)

The inner let expression binds y to the value of the x bound by the outer let. The import of m makes the definitions of x and setter visible within the inner let. The import of (A) makes the variable x exported from (A) visible as a:x within the body of the inner let. Thus, in the expression (list x a:x y z), x refers to the identifier macro exported from m while a:x refers to the variable x exported from (A) and y and z refer to the bindings established by the inner let. The identifier macro x expands into a reference to the variable z defined within the module.

With local import forms, it is rarely necessary to use the extended import specifiers. For example, an abstraction that encapsulates the import and reference can easily be defined and used as follows.

(define-syntax from
  (syntax-rules ()
    [(_ m id) (let () (import-only m) id)]))
(library (A) (export x) (import (rnrs)) (define x 1))
(let ([x 10])
  (module M (x) (define x 2))
  (cons (from (A) x) (from M x))) ⇒ (1 . 2)

The definition of from could use import rather than import-only, but by using import-only we get feedback if an attempt is made to import an identifier from a library or module that does not export the identifier. With import instead of import-only, the current binding, if any, would be visible if the library or module does not export the specified name.

(define-syntax lax-from
  (syntax-rules ()
    [(_ m id) (let () (import m) id)]))

(library (A) (export x) (import (rnrs)) (define x 1))
(let ([x 10])
  (module M (x) (define x 2))
  (+ (from (A) x) (from M y))) ⇒ exception: unbound identifier y

(let ([x 10] [y 20])
  (module M (x) (define x 2))
  (+ (lax-from (A) x) (lax-from M y))) ⇒ 21

Import visibility interacts with hygienic macro expansion in such a way that, as one might expect, an identifier \( x \) imported from a module \( M \) is treated in the importing context as if the corresponding export identifier had been present in the import form along with \( M \).

The from abstraction above works because both \( M \) and \( id \) appear in the input to the abstraction, so the imported \( id \) captures the reference to \( id \).

The following variant of from also works, because both names are introduced into the output by the transformer.

(module M (x) (define x 'x-of-M))
(define-syntax x-from-M
  (syntax-rules ()
    [(_) (let () (import M) x)]))

(let ([x 'local-x] (x-from-M)) ⇒ x-of-M

On the other hand, imports of introduced module names do not capture free references.

(let ([x 'local-x])
  (define-syntax alpha
    (syntax-rules ()
      [(_ var) (let () (import M) (list x var))])))

  (alpha x) ⇒ (x-of-M local-x)

Similarly, imports from free module names do not capture references to introduced variables.
(let ([x 'local-x])
  (define-syntax beta
    (syntax-rules ()
      [(_ m var) (let () (import m) (list x var))]))
  (beta M x)) ⇒ (local-x x-of-M)

This semantics extends to prefixed, renamed, and aliased bindings created by the extended import specifiers prefix, rename, and alias.

The from abstraction works for variables but not for exported keywords, record names, or module names, since the output is an expression and may thus appear only where expressions may appear. A generalization of this technique is used in the following definition of import*, which supports renaming of imported bindings and selective import of specific bindings—without the use of the built-in import subforms for selecting and renaming identifiers

(define-syntax import*
  (syntax-rules ()
    [(_ m) (begin)]
    [(_ m (new old))
      (module (new)
        (module (tmp)
          (import m)
          (alias tmp old))
        (alias new tmp))]
    [(_ m id) (module (id) (import m))]
    [(_ m spec0 spec1 ...) (begin (import* m spec0) (import* m spec1 ...))]))

To selectively import an identifier from module or library m, the import* form expands into an anonymous module that first imports all exports of m then re-exports only the selected identifier. To rename on import the macro expands into an anonymous module that instead exports an alias (Section 11.10) bound to the new name.

If the output placed the definition of new in the same scope as the import of m, a naming conflict would arise whenever new is also present in the interface of m. To prevent this, the output instead places the import within a nested anonymous module and links old and new by means of an alias for the introduced identifier tmp.

The macro expands recursively to handle multiple import specifications. Each of the following examples imports cons as + and + as cons, which is probably not a very good idea.

(let ()
  (import* scheme (+ cons) (cons +))
  (+ (cons 1 2) (cons 3 4))) ⇒ (3 . 7)

(let ()
  (import* (rnrs) (+ cons) (cons +))
  (+ (cons 1 2) (cons 3 4))) ⇒ (3 . 7)
(export export-spec ...)  
returns: unspecified  
libraries: (chezscheme)

An export form is a definition and can appear with other definitions at the front of a library or module. It is a syntax error for an export form to appear in other contexts, including at top level or among the definitions of a top-level program or lambda body.

Each export-spec must take one of the following forms.

identifier
(rename (internal-name export-name) ...)  
(import import-spec ...)

where each internal-name and export-name is an identifier. The first two are syntactically identical to library export-specs, while the third is syntactically identical to a Chez Scheme import form, which is an extension of the R6RS library import subform. The first form names a single export, identifier, whose export name is the same as its internal name. The second names a set of exports, each of whose export name is given explicitly and may differ from its internal name.

For the third, the identifiers identified by the import form become exports, with aliasing, renaming, prefixing, etc., as specified by the import-specs. The module or library whose bindings are exported by an import form appearing within an export form can be defined within or outside the exporting module or library and need not be imported elsewhere within the exporting module or library.

The following library exports a two-armed-only variant of if along with all remaining bindings of the (rnrs) library.

(library (rnrs-no-one-armed-if) (export)  
  (import (except (chezscheme) if)))
(export if (import (except (rnrs) if)))
(define-syntax if
  (let ()
    (import (only (rnrs) if))
    (syntax-rules ()
      [(_ tst thn els) (if tst thn els)])))

(import (rnrs-no-one-armed-if))
(if #t 3 4)  ⇒  3
(if #t 3)  ⇒  exception: invalid syntax

Another way to define the same library would be to define the two-armed-only if with a different internal name and use rename to export it under the name if:

(library (rnrs-no-one-armed-if) (export)  
  (import (chezscheme)))
(export (rename (two-armed-if if)) (import (except (rnrs) if)))
(define-syntax two-armed-if
  (syntax-rules ()
    [(_ tst thn els) (if tst thn els)])))
(import (rnrs-no-one-armed-if))
(if #t 3 4) ⇒ 3
(if #t 3) ⇒ exception: invalid syntax

The placement of the export form in the library body is irrelevant, e.g., the export form can appear after the definition in the examples above.

(indirect-export id indirect-id ...) syntax
returns: unspecified
libraries: (chezscheme)

This form is a definition and can appear wherever any other definition can appear.

An indirect-export form declares that the named indirect-ids are indirectly exported to top level if id is exported to top level.

In general, if an identifier is not directly exported by a library or module, it can be referenced outside of the library or module only in the expansion of a macro defined within and exported from the library or module. Even this cannot occur for libraries or modules defined at top level (or nested within other libraries or modules), unless either (1) the library or module has been set up to implicitly export all identifiers as indirect exports, or (2) each indirectly exported identifier is explicitly declared as an indirect export of some other identifier that is exported, either directly or indirectly, from the library or module, via an indirect-export or the built-in indirect export feature of a module export subform. By default, (1) is true for a library and false for a module, but the default can be overridden via the implicit-exports form, which is described below.

This form is meaningful only within a top-level library, top-level module, or module enclosed within a library or top-level module, although it has no effect if the library or module already implicitly exports all bindings. It is allowed anywhere else definitions can appear, however, so macros that expand into indirect export forms can be used in any definition context.

Indirect exports are listed so the compiler can determine the exact set of bindings (direct and indirect) that must be inserted into the top-level environment, and conversely, the set of bindings that may be treated more efficiently as local bindings (and perhaps discarded, if they are not used).

In the example below, indirect-export is used to indirectly export count to top level when current-count is exported to top level.

(module M (bump-count current-count)
  (define-syntax current-count (identifier-syntax count))
  (indirect-export current-count count)
  (define count 0)
  (define bump-count
    (lambda ()
      (set! count (+ count 1))))))
(import M)
(bump-count)
current-count ⇒ 1
count ⇒ exception: unbound identifier count

An indirect-export form is not required to make count visible for bump-count, since it is a procedure whose code is contained within the module rather than a macro that might expand into a reference to count somewhere outside the module.

It is often useful to use indirect-export in the output of a macro that expands into another macro named a if a expands into references to identifiers that might not be directly exported, as illustrated by the alternative definition of module M above.

(define-syntax define-counter
  (syntax-rules ()
    [(_ getter bumper init incr)
      (begin
        (define count init)
        (define-syntax getter (identifier-syntax count))
        (indirect-export getter count)
        (define bumper
          (lambda ()
            (set! count (incr count))))))])

(module M (bump-count current-count)
  (define-counter current-count bump-count 0 add1))

(implicit-exports #t)
(implicit-exports #f)
syntax
returns: unspecified
libraries: (chezscheme)

An implicit-exports form is a definition and can appear with other definitions at the front of a library or module. It is a syntax error for an implicit-exports form to appear in other contexts, including at top level or among the definitions of a top-level program or lambda body.

The implicit-exports form determines whether identifiers not directly exported from a module or library are automatically indirectly exported to the top level if any meta-binding (keyword, meta definition, or property definition) is directly exported to top level from the library or module. The default for libraries is #t, to match the behavior required by the Revised\(^6\) Report, while the default for modules is #f. The implicit-exports form is meaningful only within a library, top-level module, or module enclosed within a library or top-level module. It is allowed in a module enclosed within a lambda, let, or similar body, but ignored there because none of that module’s bindings can be exported to top level.

The advantage of (implicit-exports #t) is that indirect exports need not be listed explicitly, which is convenient. A disadvantage is that it often results in more bindings than necessary being elevated to top level where they cannot be discarded as useless by the optimizer. For modules, another disadvantage is such bindings cannot be proven immutable,
10.5. Explicitly invoking libraries

\begin{verbatim}
(invoke-library libref) procedure
returns: unspecified
libraries: (chezscheme)
\end{verbatim}

\textit{libref} must be an s-expression in the form of a library reference. The syntax for library references is given in Chapter 10 of \textit{The Scheme Programming Language, 4th Edition} and in the Revised\(^6\) Report.

A library is implicitly invoked when or before some expression outside the library (e.g., in another library or in a top-level program) evaluates a reference to one of the library’s exported variables. When the library is invoked, its body expressions (the right-hand-sides of the library’s variable definitions and its initialization expressions) are evaluated. Once invoked, the library is not invoked again within the same process, unless it is first explicitly redefined or reloaded.

\texttt{invoke-library} explicitly invokes the library specified by \textit{libref} if it has not already been invoked or has since been redefined or reloaded. If the library has not yet been loaded, \texttt{invoke-library} first loads the library via the process described in Section 2.4.

\texttt{invoke-library} is typically only useful for libraries whose body expressions have side effects. It is useful to control when the side effects occur and to force invocation of a library that has no exported variables. Invoking a library does not force the compile-time code (macro transformer expressions and meta definitions) to be loaded or evaluated, nor does it cause the library’s bindings to become visible.

It is good practice to avoid externally visible side effects in library bodies so the library can be used equally well at compile time and run time. When feasible, consider moving the side effects of a library body to an initialization routine and adding a top-level program that imports the library and calls the initialization routine. With this structure, calls to \texttt{invoke-library} on the library can be replaced by calls to \texttt{load-program} on the top-level program.

10.6. Library Parameters

The parameters described below control where \texttt{import} looks when attempting to load a library, whether it compiles the libraries it loads, and whether it displays tracking messages as it performs its search.
10. Libraries and Top-level Programs

<table>
<thead>
<tr>
<th>library-directories</th>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>library-extensions</td>
<td>thread parameter</td>
</tr>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

The parameter `library-directories` determines where the files containing library source and object code are located in the file system, and the parameter `library-extensions` determines the filename extensions for the files holding the code, as described in section 2.4. The values of both parameters are lists of pairs of strings. The first string in each `library-directories` pair identifies a source-file root directory, and the second identifies the corresponding object-file root directory. Similarly, the first string in each `library-extensions` pair identifies a source-file extension, and the second identifies the corresponding object-file extension. The full path of a library source or object file consists of the source or object root followed by the components of the library name prefixed by slashes, with the library extension added on the end. For example, for root `/usr/lib/scheme`, library name `(app lib1)`, and extension `.sls`, the full path is `/usr/lib/scheme/app/lib1.sls`. If the library name portion forms an absolute pathname, e.g., `~/.myappinit`, the `library-directories` parameter is ignored and no prefix is added.

The initial values of these parameters are shown below.

```lisp
(library-directories) ⇒ ("." . ".")
(library-extensions) ⇒ (".chezscheme.sls" . ".chezscheme.so")
                      (".ss" . ".so")
                      (".sls" . ".so")
                      (".scm" . ".so")
                      (".sch" . ".so")
```

As a convenience, when either of these parameters is set, any element of the list can be specified as a single source string, in which case the object string is determined automatically. For `library-directories`, the object string is the same as the source string, effectively naming the same directory as a source- and object-code root. For `library-extensions`, the object string is the result of removing the last (or only) extension from the string and appending ".so". The `library-directories` and `library-extensions` parameters also accept as input strings in the format described in Section 2.5 for the `--libdirs` and `--libexts` command-line options.

### compile-imported-libraries

<table>
<thead>
<tr>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
</tr>
</tbody>
</table>

When the value of this parameter is `#t`, `import` automatically calls the value of the `compile-library-handler` parameter (which defaults to a procedure that simply calls `compile-library`) on any imported library if the object file is missing, older than the corresponding source file, older than any source files included (via `include`) when the object file was created, or itself requires a library that has been or must be recompiled, as described in Section 2.4. The `library-timestamp-mode` parameter controls the meaning of “older.” The default initial value of this parameter is `#f`. It can be set to `#t` via the command-line option `--compile-imported-libraries`. 
10.6. Library Parameters

When `import` compiles a library via this mechanism, it does not also load the compiled library, because this would cause portions of library to be reevaluated. Because of this, run-time expressions in the file outside of a `library` form will not be evaluated. If such expressions are present and should be evaluated, the library should be loaded explicitly.

```
import-notify
```

<table>
<thead>
<tr>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
</tr>
</tbody>
</table>

When the new parameter `import-notify` is set to a true value, `import` displays messages to the console-output port as it searches for the file containing each library it needs to load. The default value of this parameter is `#f`.

```
library-search-handler
```

<table>
<thead>
<tr>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
</tr>
</tbody>
</table>

The value of parameter must be a procedure that follows the protocol described below for `default-library-search-handler`, which is the default value of this parameter.

The value of this parameter is invoked to locate the source or object code for a library during `import`, `compile-whole-program`, or `compile-whole-library`.

```
(default-library-search-handler who library directories extensions) procedure
```

<table>
<thead>
<tr>
<th>returns: see below</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
</tr>
</tbody>
</table>

This procedure searches the specified directories until it finds a library source or object file with one of the specified extensions. If it finds the source file first, it constructs the corresponding object file path and checks whether the file exists. If it finds the object file first, the procedure looks for a corresponding source file with one of the given source extensions in a source directory paired with that object directory. The procedure returns three values: the file-system path of the library source file or `#f` if not found, the file-system path of the corresponding object file, which may be `#f`, and a boolean that is true if the object file exists.

```
library-timestamp-mode
```

<table>
<thead>
<tr>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
</tr>
</tbody>
</table>

The value of parameter must be either `modification-time` (the default) or `exists`. If it is `modification-time`, the timestamp of library source and object files is obtained with `file-modification-time` to determine whether a file is older than the other. If
the parameter’s value is 'exists, then all files that exist are considered to have the same age. This parameter’s value can be set to 'exists via the command-line option --disable-library-timestamps.

10.7. Library Inspection

(library-list) procedure
returns: a list of the libraries currently defined
libraries: (chezscheme)

The set of libraries initially defined includes those listed in Section 10.1 above.

(library-version libref) procedure
returns: the version of the specified library

(library-exports libref) procedure
returns: a list of the exports of the specified library

(library-requirements libref) procedure
returns: a list of libraries required by the specified library

(library-requirements libref options) procedure
returns: a list of libraries required by the specified library, filtered by options

(library-object-filename libref) procedure
returns: the name of the object file holding the specified library, if any
libraries: (chezscheme)

Information can be obtained only for built-in libraries or libraries previously loaded into the system. libref must be an s-expression in the form of a library reference. The syntax for library references is given in Chapter 10 of The Scheme Programming Language, 4th Edition and in the Revised Report.

The library-version return value is a list of numbers (possibly empty) representing the library’s version.

The list of exports returned by library-exports is a list of symbols, each identifying one of the library’s exports. The order in which the elements appear is unspecified.

When the optional options argument is supplied, it must be an enumeration set over the symbols constituting valid library-requirements options, as described in the library-requirements-options entry below. It defaults to a set containing all of the options. Each element of the list of libraries returned by library-requirements is an s-expression form of a library reference. The library reference includes the actual version of the library that is present in the system (if nonempty), even if a version was not specified when it was imported. The order in which the libraries appear in the list returned by library-requirements is unspecified.

library-object-filename returns a string naming the object file if the specified library was loaded from or compiled to an object file. Otherwise, it returns #f.
(with-output-to-file "A.ss"
(lambda ()
  (pretty-print
   '(library (A (1 2)) (export x z)
     (import (rnrs))
     (define x 'ex)
     (define y 23)
     (define-syntax z
       (syntax-rules ()
         [(_ e) (+ y e)])))
   'replace)
(with-output-to-file "B.ss"
(lambda ()
  (pretty-print
   '(library (B) (export x w)
     (import (rnrs) (A))
     (define w (cons (z 12) x)))
   'replace)
(compile-imported-libraries #t)
(import (B))
(library-exports '(A)) ⇒ (x z); or (z x)
(library-exports '(A (1 2))) ⇒ (x z); or (z x)
(library-exports '(B)) ⇒ (x w); or (w x)
(library-version '(A)) ⇒ (1 2)
(library-version '(B)) ⇒ ()
(library-requirements '(A)) ⇒ ((rnrs (6)))
(library-requirements '(B)) ⇒ ((rnrs (6)) (A (1 2)))
(library-object-filename '(A)) ⇒ "A.so"
(library-object-filename '(B)) ⇒ "B.so"

(library-requirements-options symbol ...) syntax
returns: a library-requirements-options enumeration set
libraries: (chezscheme)

Library-requirements-options enumeration sets are passed to library-requirements to determine the library requirements to be listed. The available options are described below.

import: Include the libraries that must be imported when the specified library is imported.
visit@visit: Includes the libraries that must be visited when the specified library is visited.
invoke@visit: Include the libraries that must be invoked when the specified library is visited.
invoke: Includes the libraries that must be invoked when the specified library is invoked.
11. Syntactic Extension and Modules

This chapter describes the Chez Scheme extensions to the syntax-case syntactic abstraction mechanism now standardized in the Revised$^6$ Report. These extensions include the module system (Section 11.5), meta definitions (Section 11.8), conditional expansion (Section 11.9), syntax-rules fenders, fluid-let-syntax, and include.

11.1. Fluid Keyword Bindings

Keyword bindings established via the Revised$^6$ Report define-syntax, let-syntax, or letrec-syntax forms may be rebound temporarily with fluid-let-syntax.

```
(fluid-let-syntax (((keyword expr) ...) form1 form2 ...)
returns: see explanation
libraries: (chezscheme)
```

Each expr must evaluate to a transformer. fluid-let-syntax is similar to the standard let-syntax, except that instead of introducing new bindings for the keywords keyword ..., fluid-let-syntax temporarily alters the existing bindings for the keywords during the expansion of its body. That is, during the expansion of form1 form2 ..., the visible lexical (or top-level) binding for each keyword is temporarily replaced by a new association between the keyword and the corresponding transformer. This affects any references to the keyword that resolve to the same lexical (or top-level) binding whether the references occur in the text of the body or are introduced during its expansion. In contrast, let-syntax captures only those references that occur within the text of its body.

The following example shows how fluid-let-syntax differs from let-syntax.

```
(let ([f (lambda (x) (+ x 1))])
  (let-syntax ([g (syntax-rules ()
                    [(_ x) (f x)])])
    (let-syntax ([f (syntax-rules ()
                   [(_ x) x])])
      (g 1)))) → 2
```
(let ([f (lambda (x) (+ x 1))])
    (let-syntax ([g (syntax-rules ()
                      [(_: x) (f x)])])
      (fluid-let-syntax ([f (syntax-rules ()
                           [(_: x) x)])])
    (g 1))))  ⇒  1

The two expressions are identical except that the inner `let-syntax` form in the first expression is a `fluid-let-syntax` form in the second. In the first expression, the `f` occurring in the expansion of `(g 1)` refers to the `let`-bound variable `f`, whereas in the second it refers to the keyword `f` by virtue of the fluid syntax binding for `f`.

The following code employs `fluid-let-syntax` in the definition of a `define-integrable` form that is similar to `define` for procedure definitions except that it causes the code for the procedure to be integrated, or inserted, wherever a direct call to the procedure is found. No semantic difference is visible between procedures defined with `define-integrable` and those defined with `define`, except that a top-level `define-integrable` form must appear before the first reference to the defined identifier. Lexical scoping is preserved, the actual parameters in an integrated call are evaluated once and at the proper time, integrable procedures may be used as first-class values, and recursive procedures do not cause indefinite recursive expansion.

```
(define-syntax define-integrable
  (syntax-rules (lambda)
    [(_: name (lambda formals form1 form2 ...))
      (begin
        (define xname
          (fluid-let-syntax ([name (identifier-syntax xname)])
            (lambda formals form1 form2 ...)))
        (define-syntax name
          (lambda (x)
            (syntax-case x ()
              [(_: (identifier? x) #'xname]
              [(_: arg (.... ...))
                #'(fluid-let-syntax ([name (identifier-syntax xname)])
                  (lambda formals form1 form2 ...))
                arg
                  (.... ....))))))]
  )]
)
```

A `define-integrable` has the following form.

```
(define-integrable name lambda-expression)
```

A `define-integrable` form expands into a pair of definitions: a syntax definition of `name` and a variable definition of `xname`. The transformer for `name` converts apparent calls to `name` into direct calls to `lambda-expression`. Since the resulting forms are merely direct `lambda` applications (the equivalent of `let` expressions), the actual parameters are evaluated exactly once and before evaluation of the procedure’s body, as required. All other references to `name` are replaced with references to `xname`. The definition of `xname` binds it to the value of `lambda-expression`. This allows the procedure to be used as a first-class value. Because
**11.2. Syntax-Rules Transformers**

*xname* is introduced by the transformer, the binding for *xname* is not visible anywhere except where references to it are introduced by the transformer for *name*.

Within *lambda-expression*, wherever it appears, *name* is rebound to a transformer that expands all references into references to *xname*. The use of *fluid-let-syntax* for this purpose prevents indefinite expansion from indirect recursion among integrable procedures. This allows the procedure to be recursive without causing indefinite expansion. Nothing special is done by *define-integrable* to maintain lexical scoping, since lexical scoping is maintained automatically by the expander.

*Chez Scheme* integrates locally defined procedures automatically when it is appropriate to do so. It cannot integrate procedures defined at top-level, however, since code that assigns top-level variables can be introduced into the system (via *eval* or *load*) at any time. *define-integrable* can be used to force the integration of procedures bound at top-level, even if the integration of locally bound procedures is left to the compiler. It can also be used to force the integration of large procedures that the compiler would not normally integrate. (*The expand/optimize* procedure is useful for determining when integration does or does not take place.)

### 11.2. Syntax-Rules Transformers

*Chez Scheme* extends *syntax-rules* to permit clause to include fenders just like those allowed within *syntax-case* clauses.

\[
\text{(syntax-rules (literal ...) clause ...)}
\]

**syntax** returns: a transformer

**libraries:** (chezscheme)

Each *literal* must be an identifier other than an underscore (*_*) or ellipsis (*...*). Each clause must take the form below.

\[
\text{(pattern template)}
\text{(pattern fender template)}
\]

The first form is the only form supported by the Revised⁶ Report.

### 11.3. Syntax-Case Transformers

*Chez Scheme* provides several procedures and syntactic forms that may be used to simplify the coding of certain syntactic abstractions.

\[
\text{(syntax->list syntax-object)}
\]

**procedure** returns: a list of syntax objects

**libraries:** (chezscheme)

This procedure takes a syntax object representing a list-structured form and returns a list
of syntax objects, each representing the corresponding subform of the input form.

`syntax->list` may be defined as follows.

```
(define syntax->list
  (lambda (ls)
    (syntax-case ls ()
      [(() '())
       [(x . r) (cons #\'x (syntax->list #\'r))]))))
```

```
#'(a b c) ⇒ #<syntax (a b c)>
(syntax->list #'(a b c)) ⇒ (#<syntax a> #<syntax b> #<syntax c>)
```

`syntax->list` is not required for list structures constructed from individual pattern variable values or sequences of pattern-variable values, since such structures are already lists. For example:

```
(list? (with-syntax ([x #'a] [y #'b] [z #'c]) #'(x y z))) ⇒ #t
(list? (with-syntax ([(x ...) #'(a b c)]) #'(x ...))) ⇒ #t
```

### (`syntax->vector` procedure)

**returns:** a vector of syntax objects

**libraries:** (chezscheme)

This procedure takes a syntax object representing a vector-structured form and returns a vector of syntax objects, each representing the corresponding subform of the input form.

`syntax->vector` may be defined as follows.

```
(define syntax->vector
  (lambda (v)
    (syntax-case v ()
      [#(x ...) (apply vector (syntax->list #'(x ...)))])))
```

```
#'#(a b c) ⇒ #<syntax #(a b c)>
(syntax->vector #'#(a b c)) ⇒ (#<syntax a> #<syntax b> #<syntax c>)
```

`syntax->vector` is not required for vector structures constructed from individual pattern variable values or sequences of pattern-variable values, since such structures are already vectors. For example:

```
(vector? (with-syntax ([x #'a] [y #'b] [z #'c]) '#'(x y z))) ⇒ #t
(vector? (with-syntax ([(x ...) #'(a b c)]) '#'(x ...))) ⇒ #t
```

### (`syntax-object->datum` procedure)

**returns:** `obj` stripped of syntactic information

**libraries:** (chezscheme)

`syntax-object->datum` is identical to the Revised\(^6\) Report `syntax->datum`. 
11.3. Syntax-Case Transformers

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(datum template)</code></td>
<td>syntax</td>
<td>see below</td>
</tr>
</tbody>
</table>

`(datum template)` is a convenient shorthand syntax for

`(syntax->datum (syntax template))`

`datum` may be defined simply as follows.

```
(define-syntax datum
  (syntax-rules ()
    [(_ t) (syntax->datum #'t)]))
```

```
(with-syntax ((a #'(a b c))) (datum a)) ⇒ (a b c)
```

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(datum-&gt;syntax-object template-identifier obj)</code></td>
<td>a syntax object</td>
<td>(chezscheme)</td>
</tr>
</tbody>
</table>

`datum->syntax-object` is identical to the Revised\textsuperscript{6} Report `datum->syntax`.

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(with-implicit (id0 id1 ...) body1 body2 ...)</code></td>
<td>see below</td>
<td>(chezscheme)</td>
</tr>
</tbody>
</table>

This form abstracts over the common usage of `datum->syntax` for creating implicit identifiers (see above). The form

```
(with-implicit (id0 id1 ...) body1 body2 ...)
```

is equivalent to

```
(with-syntax ([id (datum->syntax #'id0 'id1)] ...) body1 body2 ...)
```

`with-implicit` can be defined simply as follows.

```
(define-syntax with-implicit
  (syntax-rules ()
    [(_ (tid id ...) b1 b2 ...) (with-syntax ([id (datum->syntax #'tid 'id)] ...) b1 b2 ...)])
```

We can use `with-implicit` to simplify the (correct version of) `loop` above.
(define-syntax loop
  (lambda (x)
    (syntax-case x ()
      [(k e ...)          
        (with-implicit (k break)
          #'(call-with-current-continuation
              (lambda (break)
                (let f () e ... (f))))))))

(include path)
returns: unspecified
libraries: (chezscheme)

path must be a string. include expands into a begin expression containing the
forms found in the file named by path. For example, if the file f-def.ss contains
(define f (lambda () x)), the expression

(let ([x "okay"]
     (include "f-def.ss")
     (f))

evaluates to "okay". An include form is treated as a definition if it appears within a
sequence of definitions and the forms on the file named by path are all definitions, as in
the above example. If the file contains expressions instead, the include form is treated as
an expression.

include may be defined portably as follows, although Chez Scheme uses an implementation-
dependent definition that allows it to capture and maintain source information for included
code.

(define-syntax include
  (lambda (x)
    (define read-file
      (lambda (fn k)
        (let ([p (open-input-file fn)])
          (let f ([x (read p)])
            (if (eof-object? x)
                (begin (close-input-port p) '())
                (cons (datum->syntax k x)
                      (f (read p))))))))
    (syntax-case x ()
      [(k filename)
        (let ([fn (datum filename)])
          (with-syntax ([[exp ...] (read-file fn #'k)]
                        #'(begin exp ...)))])))

The definition of include uses datum->syntax to convert the objects read from the file into
syntax objects in the proper lexical context, so that identifier references and definitions
within those expressions are scoped where the include form appears.
11.3. Syntax-Case Transformers

In Chez Scheme’s implementation of include, the parameter source-directories (Section 12.5) determines the set of directories searched for source files not identified by absolute path names.

\[\text{(syntax-error obj string ...)}\]

procedure
returns: does not return
libraries: (chezscheme)

Syntax errors may be reported with syntax-error, which produces a message by concatenating string ... and a printed representation of obj. If no string arguments are provided, the string "invalid syntax" is used instead. When obj is a syntax object, the syntax-object wrapper is stripped (as with syntax->datum) before the printed representation is created. If source file information is present in the syntax-object wrapper, syntax-error incorporates this information into the error message.

syntax-case and syntax-rules call syntax-error automatically if the input fails to match one of the clauses.

We can use syntax-error to precisely report the cause of the errors detected in the following definition of (unnamed) let.

\[
\begin{align*}
\text{(define-syntax let} & \quad \text{(lambda} (x) \\
\text{\quad (define} & \quad \text{check-ids!} \\
\text{\quad \quad \text{(lambda} (ls) \\
\text{\quad \quad \quad (unless} (null? ls) \\
\text{\quad \quad \quad \quad \text{(unless} \text{(identifier?} (\text{car} ls)) \\
\text{\quad \quad \quad \quad \quad \text{(syntax-error} (\text{car} ls) \text{"let cannot bind non-identifier")}) \\
\text{\quad \quad \quad \quad \quad (check-ids!} (\text{cdr} ls))) \\
\text{\quad \quad \quad \text{(define} \quad \text{check-unique!} \\
\text{\quad \quad \quad \quad \text{(lambda} (ls) \\
\text{\quad \quad \quad \quad \quad (unless} (null? ls) \\
\text{\quad \quad \quad \quad \quad \text{(let} ([x (\text{car} ls)]) \\
\text{\quad \quad \quad \quad \quad \quad \text{(when} (\text{let mem?} ([ls (\text{cdr} ls)]) \\
\text{\quad \quad \quad \quad \quad \quad \quad \text{(and} \text{(not} (null? ls)) \\
\text{\quad \quad \quad \quad \quad \quad \quad \quad \text{(or} \text{(bound-identifier=} ? x (\text{car} ls)) \\
\text{\quad \quad \quad \quad \quad \quad \quad \quad \quad \text{(mem?} (\text{cdr} ls)))) \\
\text{\quad \quad \quad \quad \quad \quad \text{(syntax-error} x \text{"let cannot bind two occurrences of")}) \\
\text{\quad \quad \quad \quad \quad \quad \text{(check-unique!} (\text{cdr} ls))) \\
\text{\quad \quad \quad \text{(syntax-case} x} (\text{)}) \\
\text{\quad \quad \quad \quad ([_ ((i e) \ldots) b1 b2 \ldots]) \\
\text{\quad \quad \quad \quad \text{(begin} \\
\text{\quad \quad \quad \quad \quad \text{(check-ids!} \#'(i \ldots)) \\
\text{\quad \quad \quad \quad \quad \text{(check-unique!} \#'(i \ldots)) \\
\text{\quad \quad \quad \quad \quad \quad \text{#'(lambda} (i \ldots) b1 b2 \ldots) e \ldots))))) \\
\end{align*}
\]

With this change, the expression

\[
\text{(let} ([a 3] [a 4]) (+ a a))
\]
produces the error message “let cannot bind two occurrences of a.”

\[(\text{literal-identifier=}? \text{identifier}_1 \text{ identifier}_2)\]  
\text{procedure}  
\text{returns: see below}  
\text{libraries: (chezscheme)}

This procedure is identical to the Revised\(^6\) Report \text{free-identifier=}?, and is provided for backward compatibility only.

### 11.4. Compile-time Values and Properties

When defining sets of dependent macros, it is often convenient to attach information to identifiers in the same compile time environment that the expander uses to record information about variables, keywords, module names, etc. For example, a record-type definition macro, like \text{define-record-type}, might need to attach information to the record-type name in the compile-time environment for use in handling child record-type definitions.

\text{Chez Scheme} provides two mechanisms for attaching information to identifiers in the compile-time environment: compile-time values and compile-time properties. A compile-time value is a kind of transformer that can be associated with an identifier via \text{define-syntax}, \text{let-syntax}, \text{letrec-syntax}, and \text{fluid-let-syntax}. When an identifier is associated with a compile-time value, it cannot also have any other meaning, and an attempt to reference it as an ordinary identifier results in a syntax error. A compile-time property, on the other hand, is maintained alongside an existing binding, providing additional information about the binding. Properties are ignored when ordinary references to an identifier occur.

The mechanisms used by a macro to obtain compile-time values and properties are similar. In both cases, the macro’s transformer returns a procedure \(p\) rather than a syntax object. The expander invokes \(p\) with one argument, an environment-lookup procedure \(\text{lookup}\), which \(p\) can then use to obtain compile-time values and properties for one or more identifiers before it constructs the macro’s final output. \(\text{lookup}\) accepts one or two identifier arguments. With one argument, \(id\), \(\text{lookup}\) returns the compile-time value of \(id\), or \#f if \(id\) has no compile-time value. With two arguments, \(id\) and \(key\), \(\text{lookup}\) returns the value of \(id\)’s \(key\) property, or \#f if \(id\) has no \(key\) property.

\[(\text{make-compile-time-value obj})\]  
\text{procedure}  
\text{returns: a compile-time value}  
\text{libraries: (chezscheme)}

A compile time value is a kind of transformer with which a keyword may be associated by any of the keyword binding constructs, e.g., \text{define-syntax} or \text{let-syntax}. The transformer encapsulates the supplied \(obj\). The encapsulated object may be retrieved as described above.
11.4. Compile-time Values and Properties

The following example illustrates how this feature might be used to define a simple syntactic record-definition mechanism where the record type descriptor is generated at expansion time.

```
(define-syntax drt
  (lambda (x)
    (define construct-name
      (lambda (template-identifier . args)
        (datum->syntax template-identifier
          (string->symbol
            (apply string-append
              (map (lambda (x)
                    (if (string? x)
                        x
                        (symbol->string (syntax->datum x)))
                 args))))))
    (define do-drt
      (lambda (rname fname* prtd)
        (with-syntax ([rname rname]
          [rtd (make-record-type-descriptor
                (syntax->datum rname) prtd #f #f #f
                (list->vector
                  (map (lambda (fname)
                        `(immutable ,(syntax->datum fname))
                          fname*))])
          [make-rname (construct-name rname "make-" rname)]
          [rname? (construct-name rname "?" )]
          [(rname-fname ...)]
          [(i ...) (enumerate fname*)]
          #'(begin
            (define-syntax rname (make-compile-time-value 'rtd))
            (define rcd (make-record-constructor-descriptor 'rtd #f #f))
            (define make-rname (record-constructor rcd))
            (define rname? (record-predicate 'rtd))
            (define rname-fname (record-accessor 'rtd i))
            (do-drt #')(rname-fname ...))]))
    (syntax-case x (parent)
      [(_ rname (fname ...))
        (for-all identifier? '#'(rname fname ...))
        (do-drt #'rname '#'(fname ...) #f)]
      [(_ rname pname (fname ...))
        (for-all identifier? '#'(rname pname fname ...))
        (lambda (lookup)
          (let ([prtd (lookup #'pname)])
            (unless (record-type-descriptor? prtd)
              (syntax-error #'pname "unrecognized parent record type")
              (do-drt #'rname '#'(fname ...) prtd))))]))
```

(drt prec (x y))
(drt crec prec (z))
(define r (make-crec 1 2 3))
(prec? r) ⇒ #t
(prec-x r) ⇒ 1
(crec-z r) ⇒ 3
prec ⇒ exception: invalid syntax prec

(compile-time-value? obj) procedure
returns: #t if obj is a compile-time value; #f otherwise
libraries: (chezscheme)

(define-syntax x (make-compile-time-value "eggs"))
(compile-time-value? (top-level-syntax 'x)) ⇒ #t

(compile-time-value-value ctv) procedure
returns: the value of a compile-time value
libraries: (chezscheme)

(define-syntax x (make-compile-time-value "eggs"))
(compile-time-value-value (top-level-syntax 'x)) ⇒ "eggs"

(define-property id key expr) syntax
returns: unspecified
libraries: (chezscheme)

A define-property form attaches a property to an existing identifier binding without disturbing the existing meaning of the identifier in the scope of that binding. It is typically used by one macro to record information about a binding for use by another macro. Both id and key must be identifiers. The expression expr is evaluated when the define-property form is expanded, and a new property associating key with the value of expr is attached to the existing binding of id, which must have a visible local or top-level binding.

define-property is a definition and can appear anywhere other definitions can appear. The scope of a property introduced by define-property is the entire body in which the define-property form appears or global if it appears at top level, except where it is replaced by a property for the same id and key or where the binding to which it is attached is shadowed. Any number of properties can be attached to the same binding with different keys. Attaching a new property with the same name as an property already attached to a binding shadows the existing property with the new property.

The following example defines a macro, get-info, that retrieves the info property of a binding, defines the variable x, attaches an info property to the binding of x, retrieves the property via get-info, references x to show that its normal binding is still intact, and uses get-info again within the scope of a different binding of x to show that the properties are shadowed as well as the outer binding of x.
11.4. Compile-time Values and Properties

(define info)
(define-syntax get-info
  (lambda (x)
    (lambda (lookup)
      (syntax-case x ()
        [(_ q)
          (let ([info-value (lookup #'q #'info)])
            #''#,(datum->syntax #'* info-value))))))

(define x "x-value")
(define-property x info "x-info")
(get-info x) ⇒ "x-info"
x ⇒ "x-value"
(let ([x "inner-x-value"] (get-info x)) ⇒ #f

For debugging, it is often useful to have a form that retrieves an arbitrary property, given
an identifier and a key. The get-property macro below does just that.

(define-syntax get-property
  (lambda (x)
    (lambda (r)
      (syntax-case x ()
        [(_ id key)
          #''#,(datum->syntax #'* (r #'id #'key))])))

(get-property x info) ⇒ "x-info"
The bindings for both identifiers must be visible where get-property is used.

The version of drt defined below is like the one defined using make-compile-time-value
above, except that it defines the record name as a macro that raises an exception with a
more descriptive message, while attaching the record type descriptor to the binding as a
separate property. The variable drt-key defined along with drt is used only as the key for
the property that drt attaches to a record name. Both drt-key and drt are defined within
a module that exports only the latter, ensuring that the properties used by drt cannot be
accessed or forged.

(library (drt) (export drt) (import (chezscheme))
(define drt-key)
(define-syntax drt
  (lambda (x)
    (define construct-name
      (lambda (template-identifier . args)
        (datum->syntax template-identifier
          (string->symbol
            (apply string-append
              (map (lambda (x)
                (if (string? x)
                  x
                  (symbol->string (syntax->datum x))))
              args))))))

(define do-drt
  (lambda (rname fname* prtd)
(with-syntax ([rname rname]
  [rtd (make-record-type-descriptor
    (syntax->datum rname) prtd #f #f #f
    list->vector
    (map (lambda (fname)
      '(immutable ,(syntax->datum fname)))
     fname*))])
  [make-rname (construct-name rname "make-" rname)]
  [rname? (construct-name rname rname "?")]
  [(rname-fname ...) (map (lambda (fname)
      (construct-name fname rname "-" fname))
     fname*)]
  [(i ...) (enumerate fname*)])

#'(begin
  (define-syntax rname
    (lambda (x)
      (syntax-error x "invalid use of record name")))
  (define rcd (make-record-constructor-descriptor 'rtd #f #f))
  (define-property rname drt-key 'rtd)
  (define make-rname (record-constructor rcd))
  (define rname? (record-predicate 'rtd))
  (define rname-fname (record-accessor 'rtd i))
  ...
))

(syntax-case x (parent)
  [( _, rname (fname ...))
   (for-all identifier? #'(rname fname ...))
   (do-drt #'rname #'(fname ...) #f)]
  [( _, rname pname (fname ...))
   (for-all identifier? #'(rname pname fname ...))
   (lambda (lookup)
     (let ([prtd (lookup #'pname #'drt-key)]
       (unless prtd
         (syntax-error #'pname "unrecognized parent record type"))
       (do-drt #'rname #'(fname ...) prtd)))]))

(import (drt))
(drt prec (x y))
(drt crec prec (z))
(define r (make-crec 1 2 3))
(prec? r) ⇒ #t
(prec-x r) ⇒ 1
(crec-z r) ⇒ 3
prec ⇒ exception: invalid use of record name prec
11.5. Modules

Modules are used to help organize programs into separate parts that interact cleanly via declared interfaces. Although modular programming is typically used to facilitate the development of large programs possibly written by many individuals, it may also be used in Chez Scheme at a “micro-modular” level, since Chez Scheme module and import forms are definitions and may appear anywhere any other kind of definition may appear, including within a lambda body or other local scope.

Modules control visibility of bindings and can be viewed as extending lexical scoping to allow more precise control over where bindings are or are not visible. Modules export identifier bindings, i.e., variable bindings, keyword bindings, or module name bindings. Modules may be named or anonymous. Bindings exported from a named module may be made visible via an import form wherever the module’s name is visible. Bindings exported from an anonymous module are implicitly imported where the module form appears. Anonymous modules are useful for hiding some of a set of bindings while allowing the remaining bindings in the set to be visible.

Some of the text and examples given in this section are adapted from the paper “Extending the scope of syntactic abstraction” [32], which describes modules and their implementation in more detail.

\[(\text{module name interface defn ... init ...})\] syntax
\[(\text{module interface defn ... init ...})\] syntax
returns: unspecified
libraries: (chezscheme)

name is an identifier, defn ... are definitions, and init ... are expressions. interface is a list of exports (export ...), where each export is either an identifier identifier or of the form (identifier export ...).

The first syntax for module establishes a named scope that encapsulates a set of identifier bindings. The exported bindings may be made visible via import or import-only (Section 10.4) anywhere the module name is visible. The second syntax for module introduces an anonymous module whose bindings are implicitly imported (as if by import of a hidden module name) where the module form appears.

A module consists of a (possibly empty) set of definitions and a (possibly empty) sequence of initialization expressions. The identifiers defined within a module are visible within the body of the module and, if exported, within the scope of an import for the module. Each identifier listed in a module’s interface must be defined within or imported into that module. A module form is a definition and can appear anywhere other definitions can appear, including at the top level of a program, nested within the bodies of lambda expressions, nested within library and top-level program forms, and nested within other modules. Also, because module names are scoped like other identifiers, modules and libraries may export module names as well as variables and keywords.

When an interface contains an export of the form (identifier export ...), only identifier is visible in the importing context. The identifiers within export ... are indirect imports,
as if declared via an **indirect-export** form (Section [10.4].

Module names occupy the same namespace as other identifiers and follow the same scoping rules. Unless exported, identifiers defined within a module are visible only within that module.

Expressions within a module can reference identifiers bound outside of the module.

```
(let ([x 3])
  (module m (plusx)
    (define plusx (lambda (y) (+ x y))))
  (import m)
  (let ([x 4])
    (plusx 5)))  ⇒  8
```

Similarly, `import` does not prevent access to identifiers that are visible where the import form appears, except for those variables shadowed by the imported identifiers.

```
(module m (y) (define y 'm-y))
(let ([x 'local-x] [y 'local-y])
  (import m)
  (list x y))  ⇒  (local-x m-y)
```

On the other hand, use of `import-only` within a module establishes an isolated scope in which the only visible identifiers are those exported by the imported module.

```
(module m (y) (define y 'm-y))
(let ([x 'local-x] [y 'local-y])
  (import-only m)
  x)  ⇒  Error: x is not visible
```

This is sometimes desirable for static verification that no identifiers are used except those explicitly imported into a module or local scope.

Unless a module imported via `import-only` exports `import` or `import-only` and the name of at least one module, subsequent imports within the scope of the `import-only` form are not possible. To create an isolated scope containing the exports of more than one module without making `import` or `import-only` visible, all of the modules to be imported must be listed in the same `import-only` form.

Another solution is to create a single module that contains the exports of each of the other modules.

```
(module m2 (y) (define y 'y))
(module m1 (x) (define x 'x))
(module mega-module (cons x y)
  (import m1)
  (import m2)
  (import scheme))
(let ([y 3])
  (import-only mega-module)
  (cons x y))  ⇒  (x . y)
```
Before it is compiled, a source program is translated into a core language program containing no syntactic abstractions, syntactic definitions, library definitions, module definitions, or import forms. Translation is performed by a *syntax expander* that processes the forms in the source program via recursive descent.

A *define-syntax* form associates a keyword with a transformer in a translation-time environment. When the expander encounters a keyword, it invokes the associated transformer and reprocesses the resulting form. A *module* form associates a module name with an interface. When the expander encounters an *import* form, it extracts the corresponding module interface from the translation-time environment and makes the exported bindings visible in the scope where the *import* form appears.

Internal definitions and definitions within a *module* body are processed from left to right so that a module's definition and import may appear within the same sequence of definitions. Expressions appearing within a body and the right-hand sides of variable definitions, however, are translated only after the entire set of definitions has been processed, allowing full mutual recursion among variable and syntactic definitions.

Module and import forms affect only the visibility of identifiers in the source program, not their meanings. In particular, variables are bound to locations whether defined within or outside of a module, and *import* does not introduce new locations. Local variables are renamed as necessary to preserve the scoping relationships established by both modules and syntactic abstractions. Thus, the expression:

\[
\begin{align*}
&\text{(let ([x 1])} \\
&\quad \text{(module m (x setter)} \\
&\quad \quad \text{(define-syntax x (identifier-syntax z))} \\
&\quad \quad \text{(define setter (lambda (x) (set! z x))} \\
&\quad \quad \text{(define z 5))} \\
&\quad \text{(let ([y x] [z 0])} \\
&\quad \quad \text{(import m)} \\
&\quad \quad \text{(setter 3)} \\
&\quad \quad \text{(+ x y z))} \Rightarrow 4
\end{align*}
\]

is equivalent to the following program in which identifiers have been consistently renamed as indicated by subscripts.

\[
\begin{align*}
&\text{(let ([x_0 1])} \\
&\quad \text{(define-syntax x_1 (identifier-syntax z_1))} \\
&\quad \text{(define setter_1 (lambda (x_2) (set! z_1 x_2))} \\
&\quad \quad \text{(define z_1 5)} \\
&\quad \text{(let ([y_3 x_0] [z_3 0])} \\
&\quad \quad \text{(setter_1 3)} \\
&\quad \quad \text{(+ x_1 y_3 z_3))}
\end{align*}
\]

Definitions within a top-level *begin*, *lambda*, top-level program, *library*, or *module* body are processed from left to right by the expander at expand time, and the variable definitions are evaluated from left-to-right at run time. Initialization expressions appearing within a *module* body are evaluated in sequence after the evaluation of the variable definitions.

Mutually recursive modules can be defined in several ways. In the following program, a
11. Syntactic Extension and Modules

and b are mutually recursive modules exported by an anonymous module whose local scope is used to statically link the two. For example, the free variable y within module a refers to the binding for y, provided by importing b, in the enclosing module.

```
(module (a b)
  (module a (x) (define x (lambda () y)))
  (module b (y) (define y (lambda () x)))
  (import a)
  (import b))
```

The following syntactic abstraction generalizes this pattern to permit the definition of multiple mutually recursive modules.

```
(define-syntax rec-modules
  (syntax-rules (module)
    [(_ (module m (id ...) form ...) ...)
      (module (m ...)
        (module m (id ...) form ...) ...
        (import m) ...)])
)
```

Because a module can re-export imported bindings, it is quite easy to provide multiple views on a single module, as s and t provide for r below, or to combine several modules into a compound, as r does.

```
(module p (x y)
  (define x 1) (define y 2))
(module q (y z)
  (define y 3) (define z 4))
(module r (a b c d)
  (import* p (a x) (b y))
  (import* q (c y) (d z)))
(module s (a c) (import r))
(module t (b d) (import r))
```

To allow interfaces to be separated from implementations, the following syntactic abstractions support the definition and use of named interfaces.

```
(define-syntax define-interface
  (syntax-rules ()
    [(_ name (export ...))
      (define-syntax name
        (lambda (x)
          (syntax-case x ()
            [(_ n defs)
              (with-implicit (n export ...) #'(module n (export ...) .
                defs))]))))
)
```

```
(define-syntax define-module
  (syntax-rules ()
    [(_ name interface defn ...)]
)
define-interface creates an interface macro that, given a module name and a list of definitions, expands into a module definition with a concrete interface.

with-implicit is used to ensure that the introduced export identifiers are visible in the same scope as the name of the module in the define-module form.

define-interface and define-module can be used as follows.

(define-interface simple (a b))
(define-module m simple
  (define-syntax a (identifier-syntax 1))
  (define b (lambda () c))
  (define c 2))
(let () (import m) (+ a (b))) ⇒ 3

The abstract module facility defined below allows a module interface to be satisfied incrementally when module forms are evaluated. This permits flexibility in the separation between the interface and implementation, supports separate compilation of mutually recursive modules, and permits redefinition of module implementations.

(define-syntax abstract-module
  (syntax-rules ()
    [(_ name (ex ...) (kwd ...) defn ...)
     (module name (ex ... kwd ...) (declare ex) ...
     defn ...))])

(define-syntax implement
  (syntax-rules ()
    [(_ name form ...)
     (module () (import name) form ...)])

Within an abstract-module form, each of the exports in the list ex ... must be variables. The values of these variables are supplied by one or more separate implement forms. Since keyword bindings must be present at compile time, they cannot be satisfied incrementally and are instead listed as separate exports and defined within the abstract module.

Within an implement form, the sequence of forms form ... is a sequence of zero or more definitions followed by a sequence of zero or more expressions. Since the module used in the expansion of implement does not export anything, the definitions are all local to the implement form. The expressions may be arbitrary expressions, but should include one satisfy form for each variable whose definition is supplied by the implement form. A satisfy form has the syntax

(satisfy variable expr)

declare and satisfy may simply be the equivalents of define and set!.

(define-syntax declare (identifier-syntax define))
(define-syntax satisfy (identifier-syntax set!))
Alternatively, `declare` can initialize the declared variable to the value of a flag known only to `declare` and `satisfy`, and `satisfy` can verify that this flag is still present to insure that only one attempt to satisfy the value of a given identifier is made.

```scheme
(module ((declare cookie) (satisfy cookie))
  (define cookie "chocolate chip")
  (define-syntax declare
    (syntax-rules () [(_ var) (define var cookie)]))
  (define-syntax satisfy
    (syntax-rules ()
      [(_ var exp)
       (if (eq? var cookie)
         (set! var exp)
         (assertion-violationf 'satisfy
          "value of variable ~s has already been satisfied" 'var))])))

Using `abstract-module` and `implement`, we can define mutually recursive and separately compilable modules as follows.

```scheme
(abstract-module e (even?) (pred)
  (define-syntax pred
    (syntax-rules () [(_ exp) (- exp 1)]))

(abstract-module o (odd?) ())

(implement e
  (import o)
  (satisfy even?
    (lambda (x)
      (or (zero? x) (odd? (pred x))))))

(implement o
  (import e)
  (satisfy odd?
    (lambda (x) (not (even? x))))))

(let () (import-only e) (even? 38)) ⇒ #t
```

These identifiers are auxiliary keywords for `import` and `import-only`. It is a syntax violation to reference these identifiers except in contexts where they are recognized as auxiliary keywords.
11.6. Standalone import and export forms

The local import and export forms described in Section 10.4 can be used equally well for
and within modules.

11.7. Built-in Modules

Five modules are built-in to Chez Scheme: scheme, r5rs, r5rs-syntax,ieee, and $system.
Each module is immutable, i.e., the exported bindings cannot be altered.

- **scheme**
  - libraries: (chezscheme)
  - scheme contains all user-visible top-level bindings (variables, keywords, and module names)
    built into Chez Scheme.

- **r5rs**
  - libraries: (chezscheme)
  - r5rs contains all top-level bindings (variables and keywords) defined in the Revised 5
    Report on Scheme. The bindings exported from r5rs are precisely those that are available
    within an expression evaluated via eval with the environment specifier returned by
    scheme-report-environment.

- **r5rs-syntax**
  - libraries: (chezscheme)
  - r5rs-syntax contains all top-level keyword bindings defined in the Revised 5
    Report on Scheme. The bindings exported from r5rs-syntax are precisely those that are available
    within an expression evaluated via eval with the environment specifier returned by
    null-environment.

- **ieee**
  - libraries: (chezscheme)
  - ieee contains all top-level bindings (variables and keywords) defined in the ANSI/IEEE
    standard for Scheme. The bindings exported from ieee are precisely those that are available
    within an expression evaluated via eval with the environment specifier returned by
    ieee-environment.

- **$system**
  - libraries: (chezscheme)
  - $system contains all user-visible top-level bindings built into Chez Scheme along with
    various undocumented system bindings.
11.8. Meta Definitions

| Function | Definition | Syntax
|----------|------------|--------|
| meta . definition | unspecified | (meta . definition) syntax
| libraries | (chezscheme) | (meta . definition) syntax

The `meta` keyword is actually a prefix that can be placed in front of any definition keyword, e.g.,

```
(meta define x 3)
```

It tells the expander that any variable definition resulting from the definition is to be an expand-time definition available only to the right-hand sides of other meta definitions and, most importantly, transformer expressions. It is used to define expand-time helpers and other information for use by one or more `syntax-case` transformers.

```
(module M (helper1 a b)
  (meta define helper1
    (lambda (---)
      ---))
  (meta define helper2
    (lambda (---)
      --- (helper2 ---) ---))
  (define-syntax a
    (lambda (x)
      --- (helper1 ---) ---))
  (define-syntax b
    (lambda (x)
      --- (helper1 ---) ---
      --- (helper2 ---) ---)))
```

The right-hand-side expressions of a syntax definition or meta definition can refer only to identifiers whose values are already available in the compile-time environment. Because of the left-to-right expansion order for `library`, `module`, `lambda`, and similar bodies, this implies a semantics similar to `let*` for a sequence of meta definitions, in which each right-hand side can refer only to the variables defined earlier in the sequence. An exception is that the right-hand side of a meta definition can refer to its own name as long as the reference is not evaluated until after the value of the expression has been computed. This permits meta definitions to be self-recursive but not mutually recursive. The right-hand side of a meta definition can, however, build syntax objects containing occurrences of any identifiers defined in the body in which the meta definition appears.

Meta definitions propagate through macro expansion, so one can write, for example:

```
(module (a)
  (meta define-record foo (x))
  (define-syntax a
    (let ([q (make-foo #’q)])
      (lambda (x) (foo-x q)))))

a ⇒ q
```
where define-record is a macro that expands into a set of defines.

It is also sometimes convenient to write

(meta begin defn ...)

or

(meta module {exports} defn ...)

or

(meta include "path")

to create groups of meta bindings.

11.9. Conditional expansion

Expansion-time decisions can be made via **meta-cond**, which is similar to **cond** but evaluates the test expressions at expansion time and can be used in contexts where definitions are expected as well as in expression contexts.

(meta-cond clause1 clause2 ...) syntax

returns: see below

libraries: (chezscheme)

Each *clause* but the last must take the form:

(test expr1 expr2 ...)

The last may take the same form or be an **else** clause of the form:

(else expr1 expr2 ...)

During expansion, the *test* expressions are evaluated in order until one evaluates to a true value or until all of the tests have been evaluated. If a *test* evaluates to a true value, the **meta-cond** form expands to a **begin** form containing the corresponding expressions *expr1 expr2 ...*. If no *test* evaluates to a true value and an **else** clause is present, the **meta-cond** form expands to a **begin** form containing the expressions *expr1 expr2 ...* from the **else** clause. Otherwise the **meta-cond** expression expands into a call to the **void** procedure.

**meta-cond** might be defined as follows.

(define-syntax meta-cond
  (syntax-rules ()
    [(_ [a0 a1 a2 ...] [b0 b1 b2 ...] ...) (let-syntax ((expr (cond
                     [a0 (identifier-syntax (begin a1 a2 ...))])
                     [b0 (identifier-syntax (begin b1 b2 ...))])])


\begin{align*}
\texttt{(meta-cond}} &\quad \texttt{[[(= \text{optimize-level} 3) \texttt{(unsafe-frob x)]}} \\
&\quad \texttt{[else \texttt{(safe-frob x)}]}}
\end{align*}

\subsection{11.10. Aliases}

\begin{tabular}{ll}
\texttt{(alias id} & \texttt{id2)} & \texttt{returns: unspecified} \\
\texttt{libraries: (chezscheme)} & \\
\end{tabular}

\texttt{alias} is a definition and can appear anywhere other definitions can appear. It is used to transfer the binding from one identifier to another.

\begin{verbatim}
(\let ([x 3]) (alias y x) (set! y 4) (list x y)) \Rightarrow (4 4)
\end{verbatim}

\begin{verbatim}
(module lisp (if)
  (module (scheme:if)
    (import scheme)
    (alias scheme:if if))
  (define-syntax if
    (syntax-rules ()
      [(_ e_1 e_2 e_3)
       (scheme:if (not (memq e_1 '(#f ()))) e_2 e_3)]))
  (define (length ls)
    (import lisp)
    (if ls (+ (length (cdr ls)) 1) 0))

(length '(a b c)) \Rightarrow 3
\end{verbatim}

Because of left-to-right expansion order, aliases should appear after the definition of the right-hand-side identifier, e.g.:

\begin{verbatim}
(let ()
  (import-only (chezscheme))
  (define y 3)
  (alias x y)
  x) \Rightarrow 3
\end{verbatim}

rather than:

\begin{verbatim}
(let ()
  (import-only (chezscheme))
  (alias x y)
\end{verbatim}
(define y 3)
x) ⇒ exception: unbound identifier

11.11. Annotations

When source code is read from a file by load, compile-file, or variants of these, such as load-library, the reader attaches annotations to each object read from the file. These annotations identify the file and the position of the object within the file. Annotations are tracked through the compilation process and associated with compiled code at run time. The expander and compiler use the annotations to produce syntax errors and compiler warnings that identify the location of the offending form, and the inspector uses them to identify the locations of calls and procedure definitions. The compiler and run time also use annotations to associate source positions with profile counts.

While these annotations are usually maintained “behind the scenes,” the programmer can manipulate them directly via a set of routines for creating and accessing annotations.

Annotations are values of a type distinct from other types and have four components: an expression, possibly with annotated subexpressions, a source object, a stripped version of the expression, and usage options. Annotations can be created via make-annotation, which has three required arguments corresponding to the first three components and an optional fourth argument corresponding to the fourth component. The second argument must be a source object, and the third argument should be a stripped version of the first argument, i.e., equivalent to the first argument with each annotation replaced by its expression component. An annotation is essentially equivalent to its stripped component as a representation of source code, with the source information attached and available to the expander or evaluator. The optional fourth argument, if present, must be an enumeration set over the symbols debug and profile and defaults to an enumeration set containing both debug and profile.

Annotations marked debug are used for compile-time error reporting and run-time error reporting and inspection; annotations marked profile are used for profiling. Annotations created by the Scheme reader are always marked both debug and profile, but other readers and parsers might choose to mark some annotations only debug or only profile. In particular, it might be useful to annotate multiple expressions in the output of a parser with the same source object for debugging purposes and mark only one of them profile to avoid duplicate counts. It might also be useful to mark no expressions profile and instead introduce explicit profile forms (Section 12.7) to identify the set of source locations to be profiled.

Source objects are also values of a type distinct from other types and also have three or five components: a source-file descriptor (sfd), a beginning file position (bfp), an ending file position (efp), an optional beginning line, and an optional beginning column. The sfd identifies the file from which an expression is read and the bfp and efp identify the range of character positions occupied by the object in the file, with the bfp being inclusive and the efp being exclusive. The line and column are either both numbers or both not present. A source object can be created via make-source-object, which takes either three or five
arguments corresponding to these components. The first argument must be a source-file descriptor, the second and third must be nonnegative exact integers, the second must not be greater than the third, and the fourth and fifth (if provided) must be positive exact integers.

Source-file descriptors are also values of a type distinct from all other types and have two components: the file’s path, usually represented by a string, and a checksum, represented by a number. The path might or might not be an absolute path depending on how the file’s path was specified when the source-file descriptor was created. The checksum is computed based on the file’s length and contents when the file is created and checked by tools that look for the source file to make sure that the proper file has been found and has not been modified. Source-file descriptors can be created with make-source-file-descriptor, which accepts two arguments: an object (usually a string) naming the path and a binary input port, along with an optional third boolean argument, reset?, which defaults to false. make-source-file-descriptor computes a checksum based on the contents of the port, starting at its current position. It resets the port, using set-port-position!, after computing the checksum if reset? is true; otherwise, it leaves the port at end-of-file.

The procedures that create, check for, and access annotations, source objects, and source-file descriptors are summarized below and described in more detail later in this section.

\[
\begin{align*}
\text{(make-annotation obj source-object obj)} & \rightarrow\ annotation \\
\text{(annotation? obj)} & \rightarrow boolean \\
\text{(annotation-expression annotation)} & \rightarrow obj \\
\text{(annotation-source annotation)} & \rightarrow source-object \\
\text{(annotation-stripped annotation)} & \rightarrow obj \\
\text{(make-source-object sfd uint uint)} & \rightarrow source-object \\
\text{(source-object? obj)} & \rightarrow boolean \\
\text{(source-object-sfd source-object)} & \rightarrow sfd \\
\text{(source-object-bfp source-object)} & \rightarrow uint \\
\text{(source-object-efp source-object)} & \rightarrow uint \\
\text{(source-object-line source-object)} & \rightarrow uint or #f \\
\text{(source-object-column source-object)} & \rightarrow uint or #f \\
\text{(make-source-file-descriptor obj binary-input-port)} & \rightarrow sfd \\
\text{(make-source-file-descriptor obj binary-input-port reset?)} & \rightarrow sfd \\
\text{(source-file-descriptor obj checksum)} & \rightarrow sfd \\
\text{(source-file-descriptor? obj)} & \rightarrow boolean \\
\text{(source-file-descriptor-checksum sfd)} & \rightarrow obj \\
\text{(source-file-descriptor-path sfd)} & \rightarrow obj
\end{align*}
\]

A program might open a source file with open-file-input-port, create an sfd using make-source-file-descriptor, create a textual port from the binary port using transcoded-port, and create source objects and annotations for each of the objects it reads from the file. If a custom reader is not required, the Scheme reader can be used to read annotations via the get-datum/annotations procedure:

\[
\text{(get-datum/annotations textual-input-port sfd uint)} \rightarrow obj, uint
\]
get-datum/annotations is like get-datum but instead of returning a plain datum, it returns an annotation encapsulating a datum (possibly with nested annotations), a source object, and the plain (stripped) datum. It also returns a second value, the position of the first character beyond the object in the file. Character positions are accepted and returned by get-datum/annotations so that the textual port need not support port-position and need not report positions in characters if it does support port-position. (Positions are usually reported in bytes.) The bfp and efp positions recorded in the annotations returned by get-datum/annotations are correct only if the positions supplied to it are correct.

Once read, an annotation can be passed to the expander, interpreter, or compiler. The procedures eval, expand, interpret, and compile all accept annotated or unannotated input.

Two additional procedures complete the set of annotation-related primitives:

(open-source-file sfd) \rightarrow \#f or port
(syntax->annotation obj) \rightarrow \#f or annotation

open-source-file attempts to locate and open the source file identified by sfd. It returns a textual input port, positioned at the beginning of the file, if successful, and \#f otherwise.

syntax->annotation accepts a syntax object. If the syntax object’s expression is annotated, it returns the annotation; otherwise, it returns \#f. It can be used by a macro to extract source information, when available, from an input form.

The procedure datum->syntax accepts either an annotated or unannotated input datum.

(make-annotation obj source-object stripped-obj) procedure
(make-annotation obj source-object stripped-obj options) procedure
returns: an annotation
libraries: (chezscheme)

The annotation is formed with obj as its expression component, source-object as its source-object component, and stripped-obj as its stripped component. obj should represent an expression, possibly with embedded annotations. stripped-obj should be a stripped version of obj, i.e., equivalent to obj with each annotation replaced by its expression component. options, if present must be an enumeration set over the symbols debug and profile, and defaults to an enumeration set containing both debug and profile. Annotations marked debug are used for compile-time error reporting and run-time error reporting and inspection; annotations marked profile are used for profiling.

(annotation? obj) procedure
returns: \#t if obj is an annotation, otherwise \#f
libraries: (chezscheme)

(annotation-expression annotation) procedure
returns: the expression component of annotation
libraries: (chezscheme)
11. Syntactic Extension and Modules

(\texttt{annotation-source \textit{annotation}}) \textbf{procedure}
returns: the source-object component of \textit{annotation}
libraries: (chezscheme)

(\texttt{annotation-stripped \textit{annotation}}) \textbf{procedure}
returns: the stripped component of \textit{annotation}
libraries: (chezscheme)

(\texttt{annotation-option-set \textit{annotation}}) \textbf{procedure}
returns: the options enumeration set of \textit{annotation}
libraries: (chezscheme)

(\texttt{make-source-object \textit{sfd} \textit{bfp} \textit{efp}}) \textbf{procedure}
(\texttt{make-source-object \textit{sfd} \textit{bfp} \textit{efp} \textit{line} \textit{column}}) \textbf{procedure}
returns: a source object
libraries: (chezscheme)

\textit{sfd} must be a source-file descriptor. \textit{bfp} and \textit{efp} must be exact nonnegative integers, and \textit{bfp} should not be greater than \textit{efp}. \textit{line} and \textit{column} must be exact positive integers.

(\texttt{source-object? \textit{obj}}) \textbf{procedure}
returns: \#t if \textit{obj} is a source object, otherwise \#f
libraries: (chezscheme)

(\texttt{source-object-sfd \textit{source-object}}) \textbf{procedure}
returns: the sfd component of \textit{source-object}
libraries: (chezscheme)

(\texttt{source-object-bfp \textit{source-object}}) \textbf{procedure}
returns: the bfp component of \textit{source-object}
libraries: (chezscheme)

(\texttt{source-object-efp \textit{source-object}}) \textbf{procedure}
returns: the efp component of \textit{source-object}
libraries: (chezscheme)

(\texttt{source-object-line \textit{source-object}}) \textbf{procedure}
returns: the line component of \textit{source-object} if present, otherwise \#f
libraries: (chezscheme)
(source-object-column source-object) procedure
returns: the column component of source-object if present, otherwise #f
libraries: (chezscheme)

current-make-source-object thread parameter
libraries: (chezscheme)

current-make-source-object is used by the reader to construct a source object for an annotation. current-make-source-object is initially bound to make-source-object, and the reader always calls the function bound to the parameter with three arguments. Adjust this parameter to, for example, eagerly convert a position integer to a file-position object, instead of delaying the conversion to locate-source.

(make-source-file-descriptor obj binary-input-port) procedure
(make-source-file-descriptor obj binary-input-port reset?) procedure
returns: a source-file descriptor
libraries: (chezscheme)

To compute the checksum encapsulated in the source-file descriptor, this procedure must read all of the data from binary-input-port. If reset? is present and #t, the port is reset to its original position, as if via port-position. Otherwise, it is left pointing at end-of-file.

(source-file-descriptor? obj) procedure
returns: #t if obj is a source-file descriptor, otherwise #f
libraries: (chezscheme)

(source-file-descriptor-checksum sfd) procedure
returns: the checksum component of sfd
libraries: (chezscheme)

(source-file-descriptor-path sfd) procedure
returns: the path component of sfd
libraries: (chezscheme)

sfd must be a source-file descriptor. The result is typically a string, but a source file descriptor can have any value representing a path.

(source-file-descriptor path checksum) procedure
returns: a new source-file-descriptor
libraries: (chezscheme)

checksum must be an exact nonnegative integer. path is usually a string, but may be any object. This procedure can be used to construct custom source-file descriptors or to reconstitute source-file descriptors from the path and checksum components.
Annotation-options enumeration sets may be passed to make-annotation to control whether the annotation is used for debugging, profiling, both, or neither. Accordingly, each symbol must be either debug or profile.

If obj is an annotation or syntax-object encapsulating an annotation, the annotation is returned.

This procedure returns two values: an annotated object and an ending file position. In most cases, bfp should be 0 for the first call to get-datum/annotation at the start of a file, and it should be the second return value of the preceding call to get-datum/annotation for each subsequent call. This protocol is necessary to handle files containing multiple-byte characters, since file positions do not necessarily correspond to character positions.

sfd must be a source-file descriptor. This procedure attempts to locate and open the source file identified by sfd. It returns a textual input port, positioned at the beginning of the file, if successful, and #f otherwise. It can fail even if a file with the correct name exists in one of the source directories when the file’s checksum does not match the checksum recorded in sfd.

This procedure either uses cached information from a previous request for sfd (only when use-cache? is provided as true) or attempts to locate and open the source file identified by sfd (which can only work when its path is a string). If successful, it returns three values:
a string path, an exact nonnegative integer line, and an exact nonnegative integer char representing the absolute pathname, line, and character position within the line represented by the specified source-file descriptor and file position. If unsuccessful, it returns zero values. It can fail even if a file with the correct name exists in one of the source directories when the file’s checksum does not match the checksum recorded in sfd.

(locate-source-object-source source-object get-start? use-cache?) procedure
returns: see below
libraries: (chezscheme)

This procedure is similar to locate-source, but instead of taking an sfd and a position, it takes a source object plus a request for either the start or end location.

If get-start? is true and source-object has a line and column, this procedure returns the path in source-objects’s sfd, source-object’s line, and source-objects’s column.

Otherwise, this procedure calls locate-source on source-object’s sfd, either source-object’s bfp or efp depending on get-start?, and use-cache?.

current-locate-source-object-source thread parameter
libraries: (chezscheme)

current-locate-source-object-source determines the source-location lookup function that is used by the system to report errors based on source objects. This parameter is initially bound to locate-source-object-object.

Adjust this parameter to control the way that source locations are extracted from source objects, possibly using recorded information, caches, and the filesystem in a way different from locate-source-object-object.

11.12. Source Tables

Source tables provide an efficient way to associate information with source objects both in memory and on disk, such as the coverage information saved to .covin files when generate-covin-files is set to #t and the profile counts associated with source objects by with-profile-tracker (Section 12.7).

Source tables are manipulated via hashtable-like accessors and setters (Section 7.14 The Scheme Programming Language, 4th Edition Section 6.13), e.g., source-table-ref and source-table-set!. They can be saved to files via put-source-table and restored via get-source-table!.

(make-source-table) procedure
returns: a source table
libraries: (chezscheme)

A source table contains associations between source objects and arbitrary values. For
purposes of the source-table operations described below, two source objects are the same if they have the same source-file descriptor, equal beginning file positions and equal ending file positions. Two source-file descriptors are the same if they have the same path and checksum.

\[
\text{(source-table? obj)} \quad \text{procedure}
\]

\text{returns: \#t if obj is a source-table; \#f otherwise}

\text{libraries: (chezscheme)}

\[
\text{(source-table-set! source-table source-object obj)} \quad \text{procedure}
\]

\text{returns: unspecified}

\text{libraries: (chezscheme)}

source-table-set! associates source-object with obj in source-table, replacing the existing association, if any.

\[
\text{(source-table-ref source-table source-object default)} \quad \text{procedure}
\]

\text{returns: see below}

\text{libraries: (chezscheme)}

\text{default may be any Scheme value.}

source-table-ref returns the value associated with source-object in source-table. If no value is associated with source-object in source-table, source-table-ref returns default.

\[
\text{(source-table-contains? source-table source-object)} \quad \text{procedure}
\]

\text{returns: \#t if an association for source-object exists in source-table, \#f otherwise}

\text{libraries: (chezscheme)}

\[
\text{(source-table-cell source-table source-object default)} \quad \text{procedure}
\]

\text{returns: a pair (see below)}

\text{libraries: (chezscheme)}

\text{default may be any Scheme value.}

If no value is associated with source-object in source-table, source-table-cell modifies source-table to associate source-object with default. Regardless, it returns a pair whose car is source-object and whose cdr is the associated value. Changing the cdr of this pair effectively updates the table to associate source-object with a new value. The car field of the pair should not be modified.

\[
\text{(source-table-delete! source-table source-object)} \quad \text{procedure}
\]

\text{returns: unspecified}

\text{libraries: (chezscheme)}

source-table-delete! drops the association for source-object from source-table, if one
exists.

`(source-table-size source-table)`  
**procedure**  
returns: the number of entries in `source-table`  
libraries: (chezscheme)

`(put-source-table textual-output-port source-table)`  
**procedure**  
returns: unspecified  
libraries: (chezscheme)

This procedure writes a representation of the information stored in `source-table` to the port.

`(get-source-table! textual-input-port source-table)`  
`(get-source-table! textual-input-port source-table combine)`  
**procedure**  
returns: unspecified  
libraries: (chezscheme)

The port must be positioned at a representation of source-table information written by some previous call to `put-source-table`, which reads the information and merges it into `source-table`.

If present and non-true, `combine` must be a procedure and should accept two arguments. It is called whenever associations for the same source object are present both in `source-table` and in the information read from the port. In this case, `combine` is passed two arguments: the associated value from `source-table` and the associated value from the port (in that order) and must return one value, which is recorded as the new associated value for the source object in `source-table`.

If `combine` is not present, `combine` is `#f`, or no association for a source object read from the port already exists in `source-table`, the value read from the port is recorded as the associated value of the source object in `source-table`.

`(define st (make-source-table))`  
`(call-with-port (open-input-file "profile.out1")`  
  `(lambda (ip) (get-source-table! ip st)))`  
`(call-with-port (open-input-file "profile.out2")`  
  `(lambda (ip) (get-source-table! ip st +))))`
12. System Operations

This chapter describes operations for handling exceptions, interrupts, environments, compilation and evaluation, profiling, controlling the operation of the system, timing and statistics, defining and setting parameters, and querying the operating system environment.

12.1. Exceptions

Chez Scheme provides some extensions to the Revised\(^6\) Report exception-handling mechanism, including mechanisms for producing formatted error messages, displaying conditions, and redefining the base exception handler. These extensions are described in this section.

\(\text{procedure} \quad \text{(warning who msg irritant ...)}\)

\text{returns: unspecified}

\text{libraries: (chezscheme)}

\text{warning} raises a continuable exception with condition type \(\texttt{&warning}\) and should be used to describe situations for which the \(\texttt{&warning}\) condition type is appropriate, typically a situation that should not prevent the program from continuing but might result in a more serious problem at some later point.

The continuation object with which the exception is raised also includes a \(\texttt{&who}\) condition whose who field is \texttt{who} if \texttt{who} is not \#f, a \(\texttt{&message}\) condition whose message field is \texttt{msg}, and an \(\texttt{&irritants}\) condition whose irritants field is \(\texttt{(irritant ...)}\).

\texttt{who} must be a string, a symbol, or \#f identifying the procedure or syntactic form reporting the warning. It is usually best to identify a procedure the programmer has called rather than some other procedure the programmer may not be aware is involved in carrying out the operation. \texttt{msg} must be a string and should describe the exceptional situation. The irritants may be any Scheme objects and should include values that may have caused or been materially involved in the exceptional situation.
These procedures are like `assertion-violation`, `error`, and `warning` except that `msg` is assumed to be a format string, as if in a call to `format` (Section 9.13), with `irritant ...` treated as the additional arguments to `format`. This allows programs to control the appearance of the error message, at least when the default exception handler is in place.

For each of these procedures, the continuation object with which the exception is raised includes a `&format` condition to signify that the string contained in the condition object’s `&message` condition is a `format` string and the objects contained in the condition object’s `&irritants` condition should be treated as the additional `format` arguments.

Presence of this condition type within a compound condition indicates that the string provided by the `&message` condition, if present, is a `format` string and the list of objects provided by the `&irritants` condition, if present, should be treated as additional `format` arguments. This condition type might be defined as follows.

```
(define-condition-type &format &condition
    make-format-condition format-condition?)
```

This condition type can be included within a compound condition when a source expression can be identified in situations in which a `&syntax` condition would be inappropriate, such as when a run-time assertion violation is detected. The `form` argument should be an s-expression or syntax object representing the source expression. This condition type might be defined as follows.

```
(define-condition-type &source &condition
    make-source-condition format-condition?)
```
(define-condition-type &continuation &condition
    make-continuation-condition continuation-condition?
    (form continuation-condition-form))

&continuation
(make-continuation-condition continuation)
syntax
returns: a condition of type &continuation
(continuation-condition? obj)
procedure
returns: #t if obj is a condition of type &continuation, #f otherwise
(condition-continuation condition)
procedure
returns: the contents of condition’s continuation field

This condition type can be included within a compound condition to indicate the current
continuation at the point where the exception described by the condition occurred. The
continuation of a failed assert or a call to assertion-violation, assertion-violationf,
error, errorf, or syntax-error is now included via this condition type in the conditions
passed to raise. The continuation argument should be a continuation. This condition
type might be defined as follows.

(define-condition-type &continuation &condition
    make-continuation-condition continuation-condition?
    (continuation-condition-continuation))

(display-condition obj)
procedure
(display-condition obj textual-output-port)
procedure
returns: unspecified
libraries: (chezscheme)

If textual-output-port is not supplied, it defaults to the current output port. This procedure
displays a message to the effect that an exception has occurred with value obj. If obj is a
formation encapsulated within the condition, handling messages, who conditions, irritants,
source information, etc., as appropriate.

(default-exception-handler obj)
procedure
returns: unspecified
libraries: (chezscheme)

This procedure is the default value of the base-exception-handler parameter called on
a condition when no other exception handler has been defined or when all dynamically
established exception handlers have chosen not to handle the condition. It first displays
obj, as if with display-condition, to the console error port. For non-serious warning
conditions, it returns immediately after displaying the condition.
For serious or other non-warning conditions, it saves the condition in the parameter `debug-condition`, where `debug` (Section 3.2) can retrieve it and allow it to be inspected. If the `debug-on-exception` parameter is set to `#f` (the default unless the `--debug-on-exception` command-line option is provided), the handler prints a message instructing the user to type `(debug)` to enter the debugger, then resets to the current café. Otherwise, the handler invokes `debug` directly and resets if `debug` returns.

If an I/O exception occurs while attempting to display the condition, the default exception handler resets (as if by calling `reset`). The intent is to avoid an infinite regression (ultimately ending in exhaustion of memory) in which the process repeatedly recurs back to the default exception handler trying to write to a console-error port (typically stderr) that is no longer writable, e.g., due to the other end of a pipe or socket having been closed.

**debug-on-exception**

This parameter determines whether the default exception handler immediately enters the debugger immediately when it receives a serious or non-warning condition. If the `--debug-on-exception` command-line option (Section 2.1) has been provided, the initial value of this parameter is `#t`. Otherwise, the initial value is `#f`.

**base-exception-handler**

The value of this parameter must be a procedure, and the procedure should accept one argument. The default value of `base-exception-handler` is the procedure `default-exception-handler`. The value of this parameter is invoked whenever no exception handler established by a program has chosen to handle an exception.

**debug-condition**

This parameter is used by the default exception handler to hold the last serious or non-warning condition received by the handler, where it can be inspected via the `debug` procedure (Section 3.2). It can also be invoked by user code to store or retrieve a condition.

**current-exception-state**

This parameter may be used to get or set the current exception state. When called without arguments, `current-exception-state` returns an exception state comprising the current stack of handlers established by `with-exception-handler` and `guard`. When called with a single argument, which must be an exception state, `current-exception-state` sets the exception state.
create-exception-state creates an exception state whose stack of exception handlers is empty except for, in effect, an infinite number of occurrences of handler at its base. handler must be a procedure, and should accept one argument. If not provided, handler defaults to a procedure equivalent to the value of the following expression.

\[
\text{(lambda} \ (x) \ ((\text{base-exception-handler}) \ x))
\]

assert-unreachable is an assertion with the special property that at optimize-level 3 the optimizer can assume that the any application of assert-unreachable is, in fact, not reachable.

In code expanded or compiled at optimize-levels less than 3, invoking assert-unreachable raises a non-continuable exception with condition type &assertion.

In code expanded or compiled at optimize-level 3, the behavior of invoking assert-unreachable is undefined, which gives the compiler liberty to pick convenient or efficient behavior. For example:

\[
\text{(print-gensym} \ #f)
\text{(optimize-level} \ 3)
\text{(expand/optimize}
\quad \text{'(lambda} \ (x)
\qquad \text{(if} \ (\text{pair?} \ x)
\qquad \qquad \text{(car} \ x)
\qquad \qquad \text{(assert-unreachable)})
\quad \text{))}
\Rightarrow \text{(lambda} \ (x) \ (#3%\text{car} \ x))
\]

because choosing to make (assert-unreachable) behave the same as (#3%car x) makes both branches of the if the same, and then pair? test can be eliminated (since it has no side effects).

12.2. Interrupts

Chez Scheme allows programs to control the action of the Scheme system when various events occur, including an interrupt from the keyboard, the expiration of an internal timer set by set-timer, a breakpoint caused by a call to break, or a request from the storage manager to initiate a garbage collection. These mechanisms are described in this section, except for the collect request mechanism, which is described in Section 13.1.

Timer, keyboard, and collect-request interrupts are supported via a counter that is decremented approximately once for each call to a nonleaf procedure. (A leaf procedure is one
that does not itself make any calls.) When no timer is running, this counter is set to a
default value (1000 in Version 9) when a program starts or after an interrupt occurs. If a
timer is set (via set-timer), the counter is set to the minimum of the default value and
the number of ticks to which the timer is set. When the counter reaches zero, the system
looks to see if the timer is set and has expired or if a keyboard or collect request inter-
rupt has occurred. If so, the current procedure call is pended (“put on hold”) while the
appropriate interrupt handler is invoked to handle the interrupt. When (if) the interrupt
handler returns, the pended call takes place. Thus, timer, keyboard, and collect-request
interrupts effectively occur synchronously with respect to the procedure call mechanism,
and keyboard and collect request interrupts may be delayed by a number of calls equal to
the default timer value.

Calls to the break handler occur immediately whenever break is called.

(break who msg irritant ...)  procedure
(break who)  procedure
(break)  procedure
returns: unspecified
libraries: (chezscheme)

The arguments to break follow the protocol described above for errorf. The default break
handler (see break-handler) displays a message and invokes the debugger. The format
string and objects may be omitted, in which case the message issued by the default break
handler identifies the break using the who argument but provides no more information
about the break. If the who argument is omitted as well, no message is generated. The
default break handler returns normally if the debugger exits normally.

break-handler  thread parameter
libraries: (chezscheme)

The value of this parameter must be a procedure. The current break handler is called by
break, which passes along its arguments. See break for a description of the default break
handler. The example below shows how to disable breaks.

(break-handler (lambda args (void)))

keyboard-interrupt-handler  thread parameter
libraries: (chezscheme)

The value of this parameter must be a procedure. The keyboard-interrupt handler is called
(with no arguments) when a keyboard interrupt occurs. The default keyboard-interrupt
handler invokes the interactive debugger. If the debugger exits normally the interrupted
computation is resumed. The example below shows how to install a keyboard-interrupt
handler that resets without invoking the debugger.
12.2. Interrupts

```
(keyboard-interrupt-handler
  (lambda ()
    (newline (console-output-port))
    (reset)))
```

```scheme
(set-timer n)
```

**procedure**

**returns:** previous current timer value

**libraries:** (chezscheme)

$n$ must be a nonnegative integer. When $n$ is nonzero, `set-timer` starts an internal timer with an initial value of $n$. When $n$ ticks elapse, a timer interrupt occurs, resulting in invocation of the timer interrupt handler. Each tick corresponds roughly to one nonleaf procedure call (see the introduction to this section); thus, ticks are not uniform time units but instead depend heavily on how much work is done by each procedure call.

When $n$ is zero, `set-timer` turns the timer off.

The value returned in either case is the value of the timer before the call to `set-timer`. A return value of 0 should not be taken to imply that the timer was not on; the return value may also be 0 if the timer was just about to fire when the call to `set-timer` occurred.

The engine mechanism (Section 6.4) is built on top of the timer interrupt so timer interrupts should not be used with engines.

```
timer-interrupt-handler
```

**thread parameter**

**libraries:** (chezscheme)

The value of this parameter must be a procedure. The timer interrupt handler is called by the system when the internal timer (set by `set-timer`) expires. The default handler raises an exception with condition type `&assertion` to say that the handler has not been defined; any program that uses the timer should redefine the handler before setting the timer.

```
(disable-interrupts)
(enable-interrupts)
```

**procedure**

**returns:** disable count

**libraries:** (chezscheme)

`disable-interrupts` disables the handling of interrupts, including timer, keyboard, and collect request interrupts. `enable-interrupts` re-enables these interrupts. The system maintains a disable count that starts at zero; when zero, interrupts are enabled. Each call to `disable-interrupts` increments the count, effectively disabling interrupts. Each call to `enable-interrupts` decrements the count, if not already zero, effectively enabling interrupts. For example, two calls to `disable-interrupts` followed by one call to `enable-interrupts` leaves interrupts disabled. Calls to `enable-interrupts` when the count is already zero (and interrupts are enabled) have no effect. The value returned by either procedure is the number of calls to `enable-interrupts` required to enable interrupts.
Great care should be exercised when using these procedures, since disabling interrupts inhibits the normal processing of keyboard interrupts, timer interrupts, and, perhaps most importantly, collect request interrupts. Since garbage collection does not happen automatically when interrupts are disabled, it is possible for the storage allocator to run out of space unnecessarily should interrupts be disabled for a long period of time.

The with-interrupts-disabled syntactic form should be used instead of these more primitive procedures whenever possible, since with-interrupts-disabled ensures that interrupts are re-enabled whenever a nonlocal exit occurs, such as when an exception is handled by the default exception handler.

(with-interrupts-disabled body₁ body₂ ...) syntax
(critical-section body₁ body₂ ...) syntax
returns: the values of the body body₁ body₂ ...
libraries: (chezscheme)

with-interrupts-disabled evaluates the body body₁ body₂ ... with interrupts disabled. That is, upon entry, interrupts are disabled, and upon exit, interrupts are re-enabled. Thus, with-interrupts-disabled allows the implementation of indivisible operations in nonthreaded versions of Chez Scheme or within a single thread in threaded versions of Chez Scheme. critical-section is the same as with-interrupts-disabled and is provided for backward compatibility.

with-interrupts-disabled can be defined as follows.

(define-syntax with-interrupts-disabled
  (syntax-rules ()
    [(_ b₁ b₂ ...) (dynamic-wind disable-interrupts (lambda () b₁ b₂ ...) enable-interrupts)]))

The use of dynamic-wind ensures that interrupts are disabled whenever the body of the with-interrupts-disabled expression is active and re-enabled whenever it is not. Since calls to disable-interrupts are counted (see the discussion under disable-interrupts and enable-interrupts above), with-interrupts-disabled expressions may be nested with the desired effect.

(register-signal-handler sig procedure) procedure
returns: unspecified
libraries: (chezscheme)

register-signal-handler is used to establish a signal handler for a given low-level signal. sig must be an exact integer identifying a valid signal, and procedure should accept one argument. See your host system’s <signal.h> or documentation for a list of valid signals and their numbers. After a signal handler for a given signal has been registered, receipt of the specified signal results in a call to the handler. The handler is passed the signal
number, allowing the same handler to be used for different signals while differentiating among them.

Signals handled in this fashion are treated like keyboard interrupts in that the handler is not called immediately when the signal is delivered to the process, but rather at some procedure call boundary after the signal is delivered. It is generally not a good idea, therefore, to establish handlers for memory faults, illegal instructions, and the like, since the code that causes the fault or illegal instruction will continue to execute (presumably erroneously) for some time before the handler is invoked. A finite amount of storage is used to buffer as-yet unhandled signals, after which additional signals are dropped.

`register-signal-handler` is supported only on Unix-based systems.

### 12.3. Environments

Environments are first-class objects containing identifier bindings. They are similar to modules but, unlike modules, may be manipulated at run time. Environments may be provided as optional arguments to `eval`, `expand`, and the procedures that define, assign, or reference top-level values.

There are several built-in environments, and new environments can be created by copying existing environments or selected bindings from existing environments.

Environments can be mutable or immutable. A mutable environment can be extended with new bindings, its existing bindings can be modified, and its variables can be assigned. An immutable environment cannot be modified in any of these ways.

```scheme
(environment? obj)  procedure
returns: #t if obj is an environment, otherwise #f
libraries: (chezscheme)
```

```scheme
(environment? (interaction-environment)) ⇒ #t
(environment? ’interaction-environment) ⇒ #f
(environment? (copy-environment (scheme-environment))) ⇒ #t
(environment? (environment ’(prefix (rnrs) $rnrs-))) ⇒ #t
```

```scheme
(environment-mutable? env)  procedure
returns: #t if env is mutable, otherwise #f
libraries: (chezscheme)
```

```scheme
(environment-mutable? (interaction-environment)) ⇒ #t
(environment-mutable? (scheme-environment)) ⇒ #f
(environment-mutable? (copy-environment (scheme-environment))) ⇒ #t
(environment-mutable? (environment ’(prefix (rnrs) $rnrs-))) ⇒ #f
```
scheme-environment returns an environment containing the initial top-level bindings. This environment corresponds to the scheme module.

The environment returned by this procedure is immutable.

(define cons 3)
(top-level-value 'cons (scheme-environment)) ⇒ #<procedure cons>
(set-top-level-value! 'cons 3 (scheme-environment)) ⇒ exception

ieee-environment returns an environment containing bindings for the keywords and variables whose meanings are defined by the IEEE/ANSI Standard for Scheme [26].

The bindings for each of the identifiers in the IEEE environment are those of the corresponding Revised6 Report library, so this does not provide full backward compatibility.

The environment returned by this procedure is immutable.

(define cons 3)
(top-level-value 'cons (ieee-environment)) ⇒ #<procedure cons>
(set-top-level-value! 'cons 3 (ieee-environment)) ⇒ exception

interaction-environment thread parameter

The original value of interaction-environment is the default top-level environment. It is initially set to a mutable copy of (scheme-environment) and which may be extended or otherwise altered by top-level definitions and assignments. It may be set to any environment, mutable or not, to change the default top-level evaluation environment.

An expression’s top-level bindings resolve to the environment that is in effect when the expression is expanded, and changing the value of this parameter has no effect on running code. Changes affect only code that is subsequently expanded, e.g., as the result of a call to eval, load, or compile-file.

(define cons 3)
cons ⇒ 3
(top-level-value 'cons (interaction-environment)) ⇒ 3

(interaction-environment (scheme-environment))
cons ⇒ #<procedure cons>
(set! cons 3) ⇒ exception: attempt to assign immutable variable
(define cons 3) ⇒ exception: invalid definition in immutable environment
12.3. Environments

(copy-environment env) procedure
(copy-environment env mutable?) procedure
(copy-environment env mutable? syms) procedure

returns: a new environment
libraries: (chezscheme)

**copy-environment** returns a copy of *env*, i.e., a new environment that contains the same bindings as *env*.

The environment is mutable if *mutable?* is omitted or true; if *mutable?* is false, the environment is immutable.

The set of bindings copied from *env* to the new environment is determined by *syms*, which defaults to the value of (environment-symbols *env*). The binding, if any, for each element of *syms* is copied to the new environment, and no other bindings are present in the new environment.

In the current implementation, the storage space used by an environment is never collected, so repeated use of **copy-environment** will eventually cause the system to run out of memory.

(define e (copy-environment (scheme-environment)))
(eval '(define cons +) e)
(eval '(cons 3 4) e) ⇒ 7
(eval '(cons 3 4) (scheme-environment)) ⇒ (3 . 4)

(environment-symbols env) procedure
returns: a list of symbols
libraries: (chezscheme)

This procedure returns a list of symbols representing the identifiers bound in environment *env*. It is primarily useful in building the list of symbols to be copied from one environment to another.

(define listless-environment
  (copy-environment
   (scheme-environment)
   #t
   (remq 'list (environment-symbols (scheme-environment))))))
(eval '(let ([x (cons 3 4)]) x) listless-environment) ⇒ (3 . 4)
(eval '(list 3 4) listless-environment) ⇒ exception

(apropos-list s) procedure
(apropos-list s env) procedure
returns: see below
libraries: (chezscheme)

This procedure returns a selected list of symbols and pairs. Each symbol in the list represents an identifier bound in *env*. Each pair represents a set of identifiers exported by a predefined library or a library previously defined or loaded into the system. The car of the
pair is the library name, and the cdr is a list of symbols. If \texttt{s} is a string, only entries whose names have \texttt{s} as a substring are included, and if \texttt{s} is a symbol, only those whose names have the name of \texttt{s} as a substring are selected. If no environment is provided, it defaults to the value of \texttt{interaction-environment}.

\begin{verbatim}
(library (a) (export a-vector-sortof) (import (rnrs))
  (define a-vector-sortof '(vector 1 2 3)))
(apropos-list 'vector-sort) ⇒
  (vector-sort vector-sort!
  ((a) a-vector-sortof)
  ((chezscheme) vector-sort vector-sort!)
  ((rnrs) vector-sort vector-sort!)
  ((rnrs sorting) vector-sort vector-sort!)
  ((scheme) vector-sort vector-sort!))
\end{verbatim}

\begin{verbatim}
(apropos s) procedure
(apropos s env) procedure
returns: unspecified
libraries: (chezscheme)
\end{verbatim}

\texttt{apropos} is like \texttt{apropos-list} except the information is displayed to the current output port, as shown in the following transcript.

\begin{verbatim}
> (library (a) (export a-vector-sortof) (import (rnrs))
  (define a-vector-sortof '(vector 1 2 3)))
> (apropos 'vector-sort)
interaction environment:
  vector-sort, vector-sort!
(a):
  a-vector-sortof
(chezscheme):
  vector-sort, vector-sort!
(rnrs):
  vector-sort, vector-sort!
(rnrs sorting):
  vector-sort, vector-sort!
(scheme):
  vector-sort, vector-sort!
\end{verbatim}

12.4. Compilation, Evaluation, and Loading

\begin{verbatim}
(eval obj) procedure
(eval obj env) procedure
returns: value of the Scheme form represented by \texttt{obj}
libraries: (chezscheme)
\end{verbatim}

eval treats \texttt{obj} as the representation of an expression. It evaluates the expression in
environment \( env \) and returns its value. If no environment is provided, it defaults to the environment returned by \texttt{interaction-environment}.

Single-argument \texttt{eval} is a \textit{Chez Scheme} extension. \textit{Chez Scheme} also permits \texttt{obj} to be the representation of a nonexpression form, i.e., a definition, whenever the environment is mutable. \textit{Chez Scheme} further allows \texttt{obj} to be an annotation (Section 11.11), and the default evaluators make use of annotations to incorporate source-file information in error messages and associate source-file information with compiled code.

In \textit{Chez Scheme}, \texttt{eval} is actually a wrapper that simply passes its arguments to the current evaluator. (See \texttt{current-eval}.) The default evaluator is \texttt{compile}, which expands the expression via the current expander (see \texttt{current-expand}), compiles it, executes the resulting code, and returns its value. If the environment argument, \texttt{env}, is present, \texttt{compile} passes it along to the current expander, which is \texttt{sc-expand} by default.

\begin{verbatim}
current-eval
libraries: (chezscheme)

\end{verbatim}

\texttt{current-eval} determines the evaluation procedure used by the procedures \texttt{eval}, \texttt{load}, and \texttt{new-cafe}. \texttt{current-eval} is initially bound to the value of \texttt{compile}. (In Petite \textit{Chez Scheme}, it is initially bound to the value of \texttt{interpret}.) The evaluation procedure should expect one or two arguments: an object to evaluate and an optional environment. The second argument might be an annotation (Section 11.11).

\begin{verbatim}
(current-eval interpret)
(+ 1 1) \Rightarrow 2

(current-eval (lambda (x . ignore) x))
(+ 1 1) \Rightarrow (+ 1 1)

(compile obj) \hspace{2cm} procedure
(compile obj env) \hspace{2cm} procedure
returns: value of the Scheme form represented by \texttt{obj}
libraries: (chezscheme)

\end{verbatim}

\texttt{obj}, which can be an annotation (Section 11.11) or unannotated value, is treated as a Scheme expression, expanded with the current expander (the value of \texttt{current-expand}) in the specified environment (or the interaction environment, if no environment is provided), compiled to machine code, and executed. \texttt{compile} is the default value of the \texttt{current-eval} parameter.

\begin{verbatim}
(interpret obj) \hspace{2cm} procedure
(interpret obj env) \hspace{2cm} procedure
returns: value of the Scheme form represented by \texttt{obj}
libraries: (chezscheme)

\end{verbatim}

\texttt{interpret} is like \texttt{compile}, except that the expression is interpreted rather than compiled. \texttt{interpret} may be used as a replacement for \texttt{compile}, with the following caveats:
• Interpreted code runs significantly slower.
• Inspector information is not generated for interpreted code, so the inspector is not as useful for interpreted code as it is for compiled code.
• Foreign procedure expressions cannot be interpreted, so the interpreter invokes the compiler for all foreign procedure expressions (this is done transparently).

interpret is sometimes faster than compile when the form to be evaluated is short running, since it avoids some of the work done by compile prior to evaluation.

(load path)  
(load path eval-proc)  
returns: unspecified  
libraries: (chezscheme)

path must be a string. load reads and evaluates the contents of the file specified by path. The file may contain source or object code. By default, load employs eval to evaluate each source expression found in a source file. If eval-proc is specified, load uses this procedure instead. eval-proc must accept one argument, the expression to evaluate. The expression passed to eval-proc might be an annotation (Section 11.11) or an unannotated value.

The eval-proc argument facilitates the implementation of embedded Scheme-like languages and the use of alternate evaluation mechanisms to be used for Scheme programs. eval-proc can be put to other uses as well. For example,

(load "myfile.ss"
  (lambda (x)
    (pretty-print
     (if (annotation? x)
        (annotation-stripped x)
        x))
    (newline)
    (eval x)))

pretty-prints each expression before evaluating it.

The parameter source-directories (Section 12.5) determines the set of directories searched for source files not identified by absolute path names or paths that start with ./ (or .\ under Windows) or ../ (or ..\ under Windows).

(load-library path)  
(load-library path eval-proc)  
returns: unspecified  
libraries: (chezscheme)

load-library is identical to load except that it treats the input file as if it were prefixed by an implicit #!r6rs. This effectively disables any non-R6RS lexical syntax except where subsequently overridden by #!chezscheme.
12.4. Compilation, Evaluation, and Loading

```
(load-program path)  procedure
(load-program path eval-proc)  procedure
returns: unspecified
libraries: (chezscheme)
```

`path` must be a string. `load-program` reads and evaluates the contents of the file specified by `path`. The file may contain source or object code. If it contains source code, `load-program` wraps the code in a `top-level-program` form so that the file’s content is treated as an RNRS top-level program (Section 10.3 of The Scheme Programming Language, 4th Edition). By default, `load-program` employs `eval` to evaluate each source expression found in the file. If `eval-proc` is specified, `load-program` uses this procedure instead. `eval-proc` must accept one argument, the expression to evaluate. The expression passed to `eval-proc` might be an annotation (Section 11.11) or an unannotated value.

The parameter `source-directories` (Section 12.5) determines the set of directories searched for source files not identified by absolute path names or paths that start with `. /` (or `. \` under Windows) or `./` (or `./` under Windows).

```
(verify-loadability situation input ...)  procedure
returns: unspecified
libraries: (chezscheme)
```

`situation` must be one of the symbols `visit`, `revisit`, or `load`. Each `input` must be a string pathname or a pair of a string pathname and a library search path. Each of the pathnames should name a file containing object code for a set of libraries and top-level programs, such as would be produced by `compile-program`, `compile-library`, `compile-whole-program`, or `compile-whole-library`. A library search path must be a suitable argument for `library-directories`.

`verify-loadability` verifies, without actually loading any code or defining any libraries, whether the object files named by the specified pathnames and their library dependencies, direct or indirect, are present, readable, and mutually compatible. The type of dependencies for each named object file is determined by the `situation` argument: compile-time dependencies for `visit`, run-time dependencies for `revisit` and both for `load`.

For each input pathname that is paired with a search path, the `library-directories` parameter is parameterized to the library search path during the recursive search for dependencies of the programs and libraries found in the object file named by the pathname.

If `verify-loadability` finds a problem, such as a missing library dependency or compilation-instance mismatch, it raises an exception with an appropriate condition. Otherwise, it returns an unspecified value.

Since `verify-loadability` does not load or run any code from the files it processes, it cannot determine whether errors unrelated to missing or unreadable files or mutual compatibility will occur when the files are actually loaded.
12. System Operations

(load-compiled-from-port input-port) procedure
(load-compiled-from-port input-port externals) procedure

returns: result of the last compiled expression
libraries: (chezscheme)

load-compiled-from-port reads and evaluates the object-code contents of input-port as previously created by functions like compile-file, compile-script, compile-library, and compile-to-port.

The externals argument, if supplied, must be a vector. It should cooperate with an ext-pred procedure passed to compile-to-port, analogous to the way a procedure and vector cooperate with fasl-write and fasl-read.

The return value is the value of the last expression whose compiled form is in input-port. If input-port is empty, then the result value is unspecified. The port is left at end-of-file but is not closed.

(visit-compiled-from-port input-port) procedure
returns: result of the last compiled expression processed
libraries: (chezscheme)

visit-compiled-from-port reads and evaluates the object-code contents of input-port as previously created by functions like compile-file, compile-script, compile-library, and compile-to-port. In the process, it skips any revisit (run-time-only) code.

The return value is the value of the last expression whose last non-revisit compiled form is in input-port. If there are no such forms, then the result value is unspecified. The port is left at end-of-file but is not closed.

(revisit-compiled-from-port input-port) procedure
returns: result of the last compiled expression processed
libraries: (chezscheme)

revisit-compiled-from-port reads and evaluates the object-code contents of input-port as previously created by functions like compile-file, compile-script, compile-library, and compile-to-port. In the process, it skips any visit (compile-time-only) code.

The return value is the value of the last expression whose last non-visit compiled form is in input-port. If there are no such forms, then the result value is unspecified. The port is left at end-of-file but is not closed.

(visit path) procedure
returns: unspecified
libraries: (chezscheme)

path must be a string. visit reads the named file, which must contain compiled object code compatible with the current machine type and version, and it runs those portions of the compiled object code that establish compile-time information or correspond to expressions identified as “visit” time by eval-when forms contained in the original source file.
For example, assume the file `t1.ss` contains the following forms:

```
(define-syntax a (identifier-syntax 3))
(module m (x) (define x 4))
(define y 5)
```

If `t1.ss` is compiled to `t1.so`, applying `load` to `t1.so` has the effect of defining all three identifiers. Applying `visit` to `t1.so`, however, has the effect of installing the transformer for `a`, installing the interface for `m` (for use by `import`), and recording `y` as a variable. `visit` is useful when separately compiling one file that depends on bindings defined in another without actually loading and evaluating the code in the supporting file.

The parameter `source-directories` (Section [12.5]) determines the set of directories searched for source files not identified by absolute path names or paths that start with `./*` (or `.\` under Windows) or `../` (or `..\` under Windows).

```
(revisit path)
```

**procedure**

**returns:** unspecified

**libraries:** `(chezscheme)`

`path` must be a string. `revisit` reads the named file, which must contain compiled object code compatible with the current machine type and version, and it runs those portions of the compiled object code that compute run-time values or correspond to expressions identified as “revisit” time by `eval-when` forms contained in the original source file.

Continuing the example given for `visit` above, applying `revisit` to the object file, `t1.so`, has the effect of establishing the values of the variable `x` exported from `m` and the top-level variable `y`, without installing either the interface for `m` or the transformer for `a`.

`revisit` is useful for loading compiled application code without loading unnecessary compile-time information. Care must be taken when using this feature if the application calls `eval` or uses `top-level-value`, `set-top-level-value!`, or `top-level-syntax` to access top-level bindings at run-time, since these procedures use compile-time information to resolve top-level bindings.

The parameter `source-directories` (Section [12.5]) determines the set of directories searched for source files not identified by absolute path names or paths that start with `./*` (or `.\` under Windows) or `../` (or `..\` under Windows).

```
(compile-file input-filename)
(compile-file input-filename output-filename)
```

**procedure**

**returns:** unspecified

**libraries:** `(chezscheme)`

`input-filename` and `output-filename` must be strings. `input-filename` must name an existing, readable file. It must contain a sequence of zero or more source expressions; if this is not the case, `compile-file` raises an exception with condition type `&syntax`.

The normal evaluation process proceeds in two steps: compilation and execution. `compile-file` performs the compilation process for an entire source file, producing an
object file. When the object file is subsequently loaded (see load), the compilation process
is not necessary, and the file typically loads several times faster.

If the optional output-filename argument is omitted, the actual input and output file-
names are determined as follows. If input-filename has no extension, the input filename is
input-filename followed by .ss and the output filename is input-filename followed by .so. If
input-filename has the extension .so, the input filename is input-filename and the output
filename is input-filename followed by .so. Otherwise, the input filename is input-filename
and the output filename is input-filename without its extension, followed by .so. For
example, (compile-file "myfile") produces an object file with the name "myfile.so"
from the source file named "myfile.ss", (compile-file "myfile.sls") produces an ob-
ject file with the name "myfile.so" from the source file named "myfile.sls", and
(compile-file "myfile1" "myfile2") produces an object file with the name "myfile2"
from the source file name "myfile1".

Before compiling a file, compile-file saves the values of the following parameters:

optimize-level
debug-level
run-cp0
cp0-effort-limit
cp0-score-limit
cp0-outer-unroll-limit
generate-inspector-information
generate-procedure-source-information
compile-profile
generate-covin-files
generate-interrupt-trap
enable-cross-library-optimization
enable-arithmetic-left-associative
enable-error-source-expression
enable-unsafe-application
enable-type-recovery

It restores the values after the file has been compiled. This allows the programmer to
control the values of these parameters on a per-file basis, e.g., via an eval-when with
situation compile embedded in the source file. For example, if

(eval-when (compile) (optimize-level 3))

appears at the top of a source file, the optimization level is set to 3 just while the remainder
of file is compiled.

(compile-script input-filename) procedure
(compile-script input-filename output-filename) procedure
returns: unspecified
libraries: (chezscheme)

input-filename and output-filename must be strings.
12.4. Compilation, Evaluation, and Loading

`compile-script` is like `compile-file` but differs in that it copies the leading `#!` line from the source-file script into the object file.

`compile-script` permits compiled script files to be created from source script to reduce script load time. As with source-code scripts, compiled scripts may be run with the `--script` command-line option.

```
(compile-library input-filename)                      procedure
(compile-library input-filename output-filename)     procedure
returns: unspecified
libraries: (chezscheme)
```

`input-filename` and `output-filename` must be strings.

`compile-library` is identical to `compile-file` except that it treats the input file as if it were prefixed by an implicit `#!r6rs`. This effectively disables any non-R6RS lexical syntax except where subsequently overridden by `#!chezscheme`.

```
(compile-program input-filename)                     procedure
(compile-program input-filename output-filename)     procedure
returns: a list of libraries invoked by the program
libraries: (chezscheme)
```

`input-filename` and `output-filename` must be strings.

`compile-program` is like `compile-script` but differs in that it implements the semantics of RNRS top-level programs, while `compile-script` implements the semantics of the interactive top-level. The resulting compiled program will also run faster than if compiled via `compile-file` or `compile-script`.

`compile-program` returns a list of libraries directly invoked by the compiled top-level program, excluding built-in libraries like `(rnrs)` and `(chezscheme)`. The procedure `library-requirements` may be used to determine the indirect requirements, i.e., additional libraries required by the directly invoked libraries. When combined with `library-object-filename`, this information can be used to determine the set of files that must be distributed with the compiled program file.

A program invokes a library only if it references one or more variables exported from the library. The set of libraries invoked by a top-level program, and hence loaded when the program is loaded, might be smaller than the set imported by the program, and it might be larger than the set directly imported by the program.

As with source-code top-level programs, compiled top-level programs may be run with the `--program` command-line option.
These procedures are like their non-maybe counterparts but compile the source file only if the object file is out-of-date. An object file \( X \) is considered out-of-date if it does not exist or if it is older than the source file or any files included (via include) when \( X \) was created. When the value of the parameter compile-imported-libraries is \#t, \( X \) is also considered out-of-date if the object file for any library imported when \( X \) was compiled is out-of-date. If maybe-compile-file determines that compilation is necessary, it compiles the source file by passing compile-file the input and output filenames. compile-library does so by similarly invoking the value of the compile-library-handler parameter, and compile-program does so by similarly invoking the value of the compile-program-handler parameter.

When output-filename is not specified, the input and output filenames are determined in the same manner as for compile-file.

This parameter must be set to a procedure, and the procedure should accept two string arguments naming a source file and an object file. The procedure should typically invoke compile-library and pass it the two arguments, but it can also use one of the other file or port compilation procedures. For example, it might read the source file using its own parser and use compile-to-file to finish the compilation process. The procedure can perform other actions as well, such as parameterizing compilation parameters, establishing guards, or gathering statistics. The default value of this parameter simply invokes compile-library on the two string arguments without taking any other action.

The value of this parameter is called by maybe-compile-library when the object file is out-of-date. It is also called by the expander to compile an imported library when compile-imported-libraries is \#t and the expander determines the object file is out-of-date.

This parameter must be set to a procedure, and the procedure should accept two string arguments naming a source file and an object file. The procedure should typically invoke compile-program and pass it the two arguments, but it can also use one of the other file or port compilation procedures. For example, it might read the source file using its own parser and use compile-to-file to finish the compilation process. The procedure can perform
other actions as well, such as parameterizing compilation parameters, establishing guards, or gathering statistics. The default value of this parameter simply invokes `compile-program` on the two string arguments without taking any other action and returns the list of libraries returned by `compile-program`.

The value of this parameter is called by `maybe-compile-program` when the object file is out-of-date.

```
(compile-whole-program input-filename output-filename)  ; procedure
(compile-whole-program input-filename output-filename libs-visible?)  ; procedure
returns: a list of libraries left to be loaded at run time
libraries: (chezscheme)
```

`compile-whole-program` accepts as input a filename naming a “whole program optimization” (wpo) file for a top-level program and produces an object file incorporating the program and each library upon which it depends, provided that a wpo file for the library can be found.

If a wpo file for a required library cannot be found, but an object file for the library can, the library is not incorporated in the resulting object file. Such libraries are left to be loaded at run time. `compile-whole-program` returns a list of such libraries. If there are no such libraries, the resulting object file is self-contained and `compile-whole-program` returns the empty list.

The libraries incorporated into the resulting object file are visible (for use by `environment` and `eval`) if the `libs-visible?` argument is supplied and non-false. Any library incorporated into the resulting object file and required by an object file left to be loaded at run time is also visible, as are any libraries the object file depends upon, regardless of the value of `libs-visible?`.

`compile-whole-program` linearizes the initialization code for the set of incorporated libraries in a way that respects static dependencies among the libraries but not necessary dynamic dependencies deriving from initialization-time uses of `environment` or `eval`. Additional static dependencies can be added in most cases to force an ordering that allows the dynamic imports to succeed, though not in general since a different order might be required each time the program is run. Adding a static dependency of one library on a second requires adding an import of the second in the first as well as a run-time reference to one of the variables exported by the second in the body of the first.

`input-filename` and `output-filename` must be strings. `input-filename` must identify a wpo file, and a wpo or object file must also be present for each required library somewhere in the directories specified by the `library-directories` parameter.

To the extent possible given the specified set of visible libraries and requirements of libraries to be loaded at run time, `compile-whole-program` discards unused code and optimizes across program and library boundaries, potentially reducing program load time, run time, and memory requirements. Some optimization also occurs even across the boundaries of libraries that are not incorporated into the output, though this optimization is limited in nature.
The procedures `compile-file`, `compile-program`, `compile-library`, `compile-script`, and `compile-whole-library` produce wpo files as well as ordinary object files when the `generate-wpo-files` parameter is set to `#t` (the default is `#f`). `compile-port` and `compile-to-port` do so when passed an optional wpo port.

```
(compile-whole-library input-filename output-filename) procedure
```

returns: a list of libraries left to be loaded at run time

libraries: (chezscheme)

`compile-whole-library` is like `compile-whole-program`, except `input-filename` must specify a wpo file for a library, all libraries are automatically made visible, and a new wpo file is produced (when `generate-wpo-files` is `#t`) as well as an object file for the resulting combination of libraries.

The comment in the description of `compile-whole-program` about the effect of initialization-code linearization on dynamic dependencies applies to `compile-whole-library` as well.

```
(compile-port input-port output-port)
(compile-port input-port output-port sfd)
(compile-port input-port output-port sfd wpo-port)
(compile-port input-port output-port sfd wpo-port covop)
```

returns: unspecified

libraries: (chezscheme)

`input-port` must be a textual input port. `output-port` and, if present and non-false, `wpo-port` must be binary output ports. If present and non-false, `sfd` must be a source-file descriptor. If present and non-false, `covop` must be a textual output port.

`compile-port` is like `compile-file` except that it takes input from an arbitrary textual input port and sends output to an arbitrary binary output port. If `sfd` is supplied, it is passed to the reader so that source information can be associated with the expressions read from `input-port`. It is also used to associate block-profiling information with the input file name encapsulated within `sfd`. If `wpo-port` is supplied, `compile-port` sends whole-program optimization information to `wpo-port` for use by `compile-whole-program`, as if (and regardless of whether) `generate-wpo-files` is set. If `covop` is supplied, `compile-port` sends coverage information to `covop`, as if (and regardless of whether) `generate-covin-files` is set.

The ports are closed automatically after compilation under the assumption the program that opens the ports and invokes `compile-port` will take care of closing the ports.
12.4. Compilation, Evaluation, and Loading

(compile-to-port objs op)  procedure
(compile-to-port objs op sfd)  procedure
(compile-to-port objs op sfd wpoop)  procedure
(compile-to-port objs op sfd wpoop covop)  procedure
(compile-to-port objs op sfd wpoop covop mach)  procedure
(compile-to-port objs op sfd wpoop covop mach hostop)  procedure
(compile-to-port objs op sfd wpoop covop mach hostop ext)  procedure
(compile-to-port objs op sfd wpoop covop mach hostop ext nortds?)  procedure

returns: see below

libraries: (chezscheme)

objs must be a list containing a sequence of objects that represent syntactically valid expressions, each possibly annotated (Section 11.11). If any of the objects does not represent a syntactically valid expression, compile-to-port raises an exception with condition type &syntax. op and, if present and non-false, wpoop, covop, and hostop must be binary output ports. If present and non-false, sfd must be a source-file descriptor. If present and non-false, mach must be a symbol. If present and non-false, ext must be or a procedure, but it must be #f if objs does not have exactly one element.

compile-to-port is like compile-file except that it takes input from a list of objects and sends output to an arbitrary binary output port. sfd is used to associate block-profiling information with the input file name encapsulated within sfd. If wpoop is present and not #f, compile-to-port sends whole-program optimization information to wpoop for use by compile-whole-program, as if (and regardless of whether) generate-wpo-files is set. If covop is present and not #f, compile-to-port sends coverage information to covop, as if (and regardless of whether) generate-covin-files is set. If mach is present, compile-to-port compiles for the specified machine type. If hostop is present, compile-to-port compiles for the host machine type to hostp (in addition to writing for machine to op, whether or not the machine types are the same).

The ports are not closed automatically after compilation under the assumption the program that opens the port and invokes compile-to-port will take care of closing the port.

If ext is present and not #f, it is used like the externals-pred predicate supplied to fasl-write. In that case, a corresponding vector must be provided to load-compiled-from-port to load the compiled code, analogous to the vector supplied to fasl-read.

Similarly, if nortds? is present and true, it is used like the omit-rtds? argument supplied to fasl-write: Any record types relevant to the compiled code are not written to the output port. When the compiled code is later loaded, these record types must already be declared in the loading context, and the loading context is assumed to have compatible record-type registrations using the same unique ID. Behavior if the loading context has an incompatible record-type registration using the same (ostensibly unique) ID is undefined.

When objs contains a single list-structured element whose first-element is the symbol top-level-program, compile-to-port returns a list of the libraries the top-level program requires at run time, as with compile-program. Otherwise, the return value is unspecified.
(compile-to-file obj-list output-file) procedure
(compile-to-file obj-list output-file sfd) procedure
returns: see below
libraries: (chezscheme)

obj-list must be a list containing a sequence of objects that represent syntactically valid expressions, each possibly annotated (Section 11.11). If any of the objects does not represent a syntactically valid expression, compile-to-file raises an exception with condition type &syntax. output-file must be a string. If present, sfd must be a source-file descriptor.

compile-to-file is like compile-file except that it takes input from a list of objects. sfd is used to associate block-profiling information with the input file name encapsulated within sfd.

When obj-list contains a single list-structured element whose first-element is the symbol top-level-program, compile-to-file returns a list of the libraries the top-level program requires at run time, as with compile-program. Otherwise, the return value is unspecified.

(concatenate-object-files out-file in-file1 in-file2 ...) procedure
returns: unspecified
libraries: (chezscheme)

out-file and each in-file must be strings.

concatenate-object-files combines the header information contained in the object files named by each in-file. It then writes the combined header information to the file named by out-file, followed by the remaining object code from each input file in turn.

(make-boot-file output-filename base-boot-list input-filename ...) procedure
returns: unspecified
libraries: (chezscheme)

output-filename, input-filename, and the elements of base-boot-list must be strings.

make-boot-file writes a boot header to the file named by output-filename, followed by the object code for each input-filename in turn. If an input file is not already compiled, make-boot-file compiles the file as it proceeds.

The boot header identifies the elements of base-boot-list as alternative boot files upon which the new boot file depends. If the list of strings naming base boot files is empty, the first named input file should be a base boot file, i.e., petite.boot or some boot file derived from petite.boot.

Boot files are loaded explicitly via the --boot or -b command-line options or implicitly based on the name of the executable (Section 2.9).

See Section 2.8 for more information on boot files and the use of make-boot-file.
12.4. Compilation, Evaluation, and Loading

\begin{verbatim}
(make-boot-header output-filename base-boot1 base-boot2...)  procedure

returns: unspecified

libraries: (chezscheme)

This procedure has been subsumed by make-boot-file and is provided for backward compatibility. The call

(make-boot-header output-filename base-boot1 base-boot2 ...)

is equivalent to

(make-boot-file output-filename '(base-boot1 base-boot2 ...))

(strip-fasl-file input-path output-path options)  procedure

returns: unspecified

libraries: (chezscheme)

input-path and output-path must be strings. input-path must name an existing, readable file containing object code produced by compile-file, one of the other file-compiling procedures, or an earlier run of strip-fasl-file. options must be an enumeration set over the symbols constituting valid strip options, as described in the fasl-strip-options entry below.

The new procedure strip-fasl-file allows the removal of source information of various sorts from a compiled object (fasl) file produced by compile-file or one of the other file compiling procedures. It also allows removal of library visit code from object files containing compiled libraries. Visit code is the code for macro transformers and meta definitions required to compile (but not run) dependent libraries.

On most platforms, the input and output paths can be the same, in which case the input file is replaced with a new file containing the stripped object code. Using the same path will likely fail on Windows file systems, which do not generally permit an open file to be removed.

If options is empty, the output file is effectively equivalent to the input file, though it will not necessarily be identical.

(fasl-strip-options symbol ...)  syntax

returns: a fasl-strip-options enumeration set

libraries: (chezscheme)

Fasl-strip-options enumeration sets are passed to strip-fasl-file to determine what is stripped. The available options are described below.

inspector-source: Strip inspector source information. This includes source expressions that might otherwise be available for procedures and continuations with the “code” and “call” commands and messages in the interactive and object inspectors. It also includes filename and position information that might otherwise be available for the same via the “file” command and “source” messages.
source-annotations: Strip source annotations, which typically appear only on syntax objects, e.g., identifiers, in the templates of macro transformers.

profile-source: Strip source file and character position information from profiled code objects. This does not remove the profile counters or eliminate the overhead for incrementing them at run time.

compile-time-information: This strips compile-time information from compiled libraries, potentially reducing the size of the resulting file but making it impossible to use the file to compile dependent code. This option is useful for creating smaller object files to ship as part of a binary-only package.

compile-procedure-realm thread parameter
libraries: (chezscheme)

This parameter can be set to #f or to a symbol. The realm of a procedure (or, more precisely, a procedure’s code object) is accessible though the inspector.

(vfasl-convert-file input-path output-path base-boots) procedure
returns: unspecified
libraries: (chezscheme)

Converts a compiled file to one that may load more quickly, especially in the case of a boot file. The converted file is a boot file if base-boots is a list of strings, otherwise base-boots must be #f to create a non-boot file.

(pbchunk-convert-file in-path out-path c-paths c-names start-index) procedure
returns: ending index as a nonnegative exact integer
libraries: (chezscheme)

Converts a compiled file in-path for a pb machine variant to a compiled file out-path that uses C chunk functions written to the files in c-paths, where c-paths is a nonempty list of file names. Chunk code is distributed across the files to avoid making a single, over-large source C file. The c-names list provides a list of function names, one for each output file in c-paths, where each function name is defined as a function of no arguments to register the file’s chunks with the system. This registration must be performed before the converted compiled code is run. Every set of chunks registered in this way must use a distinct index range, where start-index provides the starting index for this set, and the result value is one more than the index of the last chunk written to the c-paths sources.

(machine-type) procedure
returns: the current machine type
libraries: (chezscheme)

Consult the release notes for the current version of Chez Scheme for a list of supported machine types.
12.4. Compilation, Evaluation, and Loading

(expand obj) procedure
(expand obj env) procedure
returns: expansion of the Scheme form represented by obj
libraries: (chezscheme)

expand treats obj as the representation of an expression. It expands the expression in environment env and returns an object representing the expanded form. If no environment is provided, it defaults to the environment returned by interaction-environment.

obj can be an annotation (Section 11.11), and the default expander makes use of annotations to incorporate source-file information in error messages.

expand actually passes its arguments to the current expander (see current-expand), initially sc-expand.

See also expand-output (page 396) which can be used to request that the compiler or interpreter show expander output.

current-expand thread parameter
libraries: (chezscheme)

current-expand determines the expansion procedure used by the compiler, interpreter, and direct calls to expand to expand syntactic extensions. current-expand is initially bound to the value of sc-expand.

It may be set another procedure, but since the format of expanded code expected by the compiler and interpreter is not publicly documented, only sc-expand produces correct output, so the other procedure must ultimately be defined in terms of sc-expand.

The first argument to the expansion procedure represents the input expression. It can be an annotation (Section 11.11) or an unannotated value. The second argument is an environment. Additional arguments might be passed to the expansion procedure by the compiler, interpreter, and expand; their number and roles are unspecified.

(sc-expand obj) procedure
(sc-expand obj env) procedure
returns: the expanded form of obj
libraries: (chezscheme)

The procedure sc-expand is used to expand programs written using syntax-case macros. sc-expand is the default expander, i.e., the initial value of current-expand. obj represents the program to be expanded, and env must be an environment. obj can be an annotation (Section 11.11) or unannotated value. If not provided, env defaults to the environment returned by interaction-environment.
(expand/optimize obj)  \hspace{1cm} \text{procedure}
(\text{expand/optimize} \ obj \ env)  \hspace{1cm} \text{procedure}

\text{return}s: result of expanding and optimizing form represented by \text{obj}
libraries: (chezscheme)

\text{expand/optimize} \ \text{treats} \ \text{obj} \ \text{as the representation of an expression}. \ \text{obj} \ \text{can be an annotation} \ (\text{Section} \ 11.11) \ \text{or unannotated value}. \ \text{expand/optimize} \ \text{expands the expression in environment} \ \text{env} \ \text{and passes the expression through the source optimizer} \ \text{cp0} \ \text{and a type-inferring optimizer} \ \text{cptypes} \ (\text{unless} \ \text{cp0} \ \text{and} \ \text{cptypes} \ \text{are disabled via} \ \text{run-cp0}, \ \text{or unless} \ \text{cptypes} \ \text{is disabled via} \ \text{enable-type-recovery}). \ \text{It also simplifies} \ \text{letrec} \ \text{and letrec* expressions within the expression and makes their undefined checks explicit}. \ \text{It returns an object representing the expanded, simplified, and optimized form}. \ \text{If no environment is provided, it defaults to the environment returned by} \ \text{interaction-environment}.

\text{expand/optimize} \ \text{is primarily useful for understanding what} \ \text{cp0} \ \text{plus} \ \text{cptypes} \ \text{does and does not optimize}. \ \text{Many optimizations are performed later in the compiler, so} \ \text{expand/optimize} \ \text{does not give a complete picture of optimizations performed}.

\begin{verbatim}
(\text{expand/optimize}
 \quad '(let ([y '(3 . 4)])
 \quad \quad (+ (car y) (cdr y)))) \Rightarrow 7

(\text{print-gensym} \ #f)
(\text{expand/optimize}
 \quad '(let ([y '(3 . 4)])
 \quad \quad (lambda (x)
 \quad \quad \quad (* (+ (car y) (cdr y)) x)))) \Rightarrow (lambda (x) (#2%* 7 x))

(\text{expand/optimize}
 \quad '(let ([n (expt 2 10)])
 \quad \quad (define even?
 \quad \quad \quad (lambda (x) (or (zero? x) (not (odd? x))))))
 \quad \quad (define odd?
 \quad \quad \quad (lambda (x) (not (even? (- x 1))))))
 \quad \quad (define f
 \quad \quad \quad (lambda (x)
 \quad \quad \quad \quad (lambda (y)
 \quad \quad \quad \quad \quad (lambda (z)
 \quad \quad \quad \quad \quad \quad \quad (if (= z 0) (omega) (+ x y z)))))))
 \quad \quad (define omega
 \quad \quad \quad (lambda ()
 \quad \quad \quad \quad ((lambda (x) (x x)) (lambda (x) (x x))))))
 \quad \quad (let ([g (f 1)] [m (f n)])
 \quad \quad \quad (let ([h (if (> ((g 2) 3) 5)
 \quad \quad \quad \quad \quad (lambda (x) (+ x 1))
 \quad \quad \quad \quad \quad \quad \quad odd?))]
 \quad \quad \quad \quad (h n))))) \Rightarrow 1025
\end{verbatim}

\text{See also} \ \text{expand/optimize-output} \ (\text{page} \ 396) \ \text{which can be used to request that the compiler or interpreter show source-optimizer output}.
12.4. Compilation, Evaluation, and Loading

(situations in eval-when)

(syntax returns: see below)

(libraries: (chezscheme))

situations must be a list containing some combination of the symbols eval, compile, load, visit, and revisit.

When source files are loaded (see load), the forms in the file are read, compiled, and executed sequentially, so that each form in the file is fully evaluated before the next one is read. When a source file is compiled (see compile-file), however, the forms are read and compiled, but not executed, in sequence. This distinction matters only when the execution of one form in the file affects the compilation of later forms, e.g., when the form results in the definition of a module or syntactic form or sets a compilation parameter such as optimize-level or case-sensitive.

For example, assume that a file contains the following two forms:

(define-syntax reverse-define
  (syntax-rules ()
    [(_ e x) (define x e)]))

(reverse-define 3 three)

Loading this from source has the effect of defining reverse-define as a syntactic form and binding the identifier three to 3. The situation may be different if the file is compiled with compile-file, however. Unless the system or programmer takes steps to assure that the first form is fully executed before the second expression is compiled, the syntax expander will not recognize reverse-define as a syntactic form and will generate code for a procedure call to reverse-define instead of generating code to define three to be 3. When the object file is subsequently loaded, the attempt to reference either reverse-define or three will fail.

As it happens, when a define-syntax, module, import, or import-only form appears at top level, as in the example above, the compiler does indeed arrange to evaluate it before going on to compile the remainder of the file. If the compiler encounters a variable definition for an identifier that was previously something else, it records that fact as well. The compiler also generates the appropriate code so that the bindings will be present as well when the object file is subsequently loaded. This solves most, but not all, problems of this nature, since most are related to the use of define-syntax and modules. Some problems are not so straightforwardly handled, however. For example, assume that the file contains the following definitions for nodups? and mvlet.

(define nodups?
  (lambda (ids)
    (define bound-id-member?
      (lambda (id ids)
        (and (not (null? ids))
          (or (bound-identifier=? id (car ids))
            (bound-id-member? id (cdr ids)))))))

(or (null? ids)
(define-syntax mvlet
  (syntax-case x ()
    [(_ ((x ...) expr) b1 b2 ...)
      (and (andmap identifier? #'(x ...))
        (nodups? #'(x ...))
        #'(call-with-values
          (lambda () expr)
          (lambda (x ...) b1 b2 ...)))]))

(mvlet ((a b c) (values 1 2 3))
  (list (* a a) (* b b) (* c c)))

When loaded directly, this results in the definition of nodups? as a procedure and mvlet as a syntactic abstraction before evaluation of the mvlet expression. Because nodups? is defined before the mvlet expression is expanded, the call to nodups? during the expansion of mvlet causes no difficulty. If instead this file were compiled, using compile-file, the compiler would arrange to define mvlet before continuing with the expansion and evaluation of the mvlet expression, but it would not arrange to define nodups?. Thus the expansion of the mvlet expression would fail.

In this case it does not help to evaluate the syntactic extension alone. A solution in this case would be to move the definition of nodups? inside the definition for mvlet, just as the definition for bound-id-member? is placed within nodups?, but this does not work for help routines shared among several syntactic definitions. Another solution is to label the nodups? definition a “meta” definition (see Section 11.8) but this does not work for helpers that are used both by syntactic abstractions and by run-time code.

A somewhat simpler problem occurs when setting parameters that affect compilation, such as optimize-level and case-sensitive?. If not set prior to compilation, their settings usually will not have the desired effect.

eval-when offers a solution to these problems by allowing the programmer to explicitly control what forms should or should not be evaluated during compilation. eval-when is a syntactic form and is handled directly by the expander. The action of eval-when depends upon the situations argument and whether or not the forms form1 form2 ... are being compiled via compile-file or are being evaluated directly. Let’s consider each of the possible situation specifiers eval, compile, load, visit, and revisit in turn.

eval: The eval specifier is relevant only when the eval-when form is being evaluated directly, i.e., if it is typed at the keyboard or loaded from a source file. Its presence causes form1 form2 ... to be expanded and this expansion to be included in the expansion of the eval-when form. Thus, the forms will be evaluated directly as if not contained within an eval-when form.

compile: The compile specifier is relevant only when the eval-when form appears in a file currently being compiled. (Its presence is simply ignored otherwise.) Its presence forces form1 form2 ... to be expanded and evaluated immediately.
load: The load specifier is also relevant only when the eval-when form appears in a file currently being compiled. Its presence causes \( \text{form}_1 \ \text{form}_2 \ \ldots \) to be expanded and this expansion to be included in the expansion of the eval-when form. Any code necessary to record binding information and evaluate syntax transformers for definitions contained in the forms is marked for execution when the file is “visited,” and any code necessary to compute the values of variable definitions and the expressions contained within the forms is marked for execution when the file is “revisited.”

visit: The visit specifier is also relevant only when the eval-when form appears in a file currently being compiled. Its presence causes \( \text{form}_1 \ \text{form}_2 \ \ldots \) to be expanded and this expansion to be included in the expansion of the eval-when form, with an annotation that the forms are to be executed when the file is “visited.”

revisit: The revisit specifier is also relevant only when the eval-when form appears in a file currently being compiled. Its presence causes \( \text{form}_1 \ \text{form}_2 \ \ldots \) to be expanded and this expansion to be included in the expansion of the eval-when form, with an annotation that the forms are to be executed when the file is “revisited.”

A file is considered “visited” when it is brought in by either load or visit and “revisited” when it is brought in by either load or revisit.

Top-level expressions are treated as if they are wrapped in an eval-when with situations load and eval. This means that, by default, forms typed at the keyboard or loaded from a source file are evaluated, and forms appearing in a file to be compiled are not evaluated directly but are compiled for execution when the resulting object file is subsequently loaded.

The treatment of top-level definitions is slightly more involved. All definitions result in changes to the compile-time environment. For example, an identifier defined by define is recorded as a variable, and an identifier defined by define-syntax is recorded as a keyword and associated with the value of its right-hand-side (transformer) expression. These changes are made at eval, compile, and load time as if the definitions were wrapped in an eval-when with situations eval, load, and compile. (This behavior can be altered by changing the value of the parameter eval-syntax-expanders-when.) Some definitions also result in changes to the run-time environment. For example, a variable is associated with the value of its right-hand-side expression. These changes are made just at evaluation and load time as if the definitions were wrapped in an eval-when with situations eval and load.

The treatment of local expressions or definitions (those not at top level) that are wrapped in an eval-when depends only upon whether the situation eval is present in the list of situations. If the situation eval is present, the definitions and expressions are evaluated as if they were not wrapped in an eval-when form, i.e., the eval-when form is treated as a begin form. If the situation eval is not present, the forms are ignored; in a definition context, the eval-when form is treated as an empty begin, and in an expression context, the eval-when form is treated as a constant with an unspecified value.

Since top-level syntax bindings are established, by default, at compile time as well as eval and load time, top-level variable bindings needed by syntax transformers should be wrapped in an eval-when form with situations compile, load, and eval. We can thus nodups? problem above by enclosing the definition of nodups? in an eval-when as follows.
define nodups?
  (lambda (ids)
    (define bound-id-member?
      (lambda (id ids)
        (and (not (null? ids))
          (or (bound-identifier=? id (car ids))
              (bound-id-member? id (cdr ids))))))
    (or (null? ids)
        (and (not (bound-id-member? (car ids) (cdr ids)))
              (nodups? (cdr ids))))))

This forces it to be evaluated before it is needed during the expansion of the `mvlet` expression.

Just as it is useful to add `compile` to the default `load` and `eval` situations, omitting options is also useful. Omitting one or more of `compile`, `load`, and `eval` has the effect of preventing the evaluation at the given time. Omitting all of the options has the effect of inhibiting evaluation altogether.

One common combination of situations is `(compile eval)`, which by the inclusion of `compile` causes the expression to be evaluated at compile time, and by the omission of `load` inhibits the generation of code by the compiler for execution when the file is subsequently loaded. This is typically used for the definition of syntactic extensions used only within the file in which they appear; in this case their presence in the object file is not necessary. It is also used to set compilation parameters that are intended to be in effect whether the file is loaded from source or compiled via `compile-file`

```
(eval-when (compile eval) (case-sensitive #t))
```

Another common situations list is `(compile)`, which might be used to set compilation options to be used only when the file is compiled via `compile-file`.

```
(eval-when (compile) (optimize-level 3))
```

Finally, one other common combination is `(load eval)`, which might be useful for inhibiting the double evaluation (during the compilation of a file and again when the resulting object file is loaded) of syntax definitions when the syntactic extensions are not needed within the file in which their definitions appear.

The behavior of `eval-when` is usually intuitive but can be understood precisely as follows. The `syntax-case` expander, which handles `eval-when` forms, maintains two state sets, one for compile-time forms and one for run-time forms. The set of possible states in each set are “L” for `load`, “C” for `compile`, “V” for `visit`, “R” for `revisit`, and “E” for `eval`.

When compiling a file, the compile-time set initially contains “L” and “C” and the runtime set initially contains only “L.” When not compiling a file (as when a form is evaluated by the read-eval-print loop or loaded from a source file), both sets initially contain only “E.” The subforms of an `eval-when` form at top level are expanded with new compile- and run-time sets determined by the current sets and the situations listed in the `eval-when` form. Each element of the current set contributes zero or more elements to the new set.
depending upon the given situations according to the following table.

<table>
<thead>
<tr>
<th></th>
<th>load</th>
<th>compile</th>
<th>visit</th>
<th>revisit</th>
<th>eval</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>C</td>
<td>V</td>
<td>R</td>
<td>—</td>
</tr>
<tr>
<td>C</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>C</td>
</tr>
<tr>
<td>V</td>
<td>V</td>
<td>C</td>
<td>V</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>R</td>
<td>R</td>
<td>C</td>
<td>—</td>
<td>R</td>
<td>—</td>
</tr>
<tr>
<td>E</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>E</td>
</tr>
</tbody>
</table>

For example, if the current compile-time state set is \{L\} and the situations are load and compile, the new compile-time state set is \{L, C\}, since L/load contributes “L” and L/compile contributes “C.”

The state sets determine how forms are treated by the expander. Compile-time forms such as syntax definitions are evaluated at a time or times determined by the compile-time state set, and run-time forms are evaluated at a time or times determined by the run-time state set. A form is evaluated immediately if “C” is in the state set. Code is generated to evaluate the form at visit or revisit time if “V” or “R” is present. If “L” is present in the compile-time set, it is treated as “V;” likewise, if “L” is present in the run-time set, it is treated as “R.” If more than one of states is present in the state set, the form is evaluated at each specified time.

“E” can appear in the state set only when not compiling a file, i.e., when the expander is invoked from an evaluator such as compile or interpret. When it does appear, the expanded form is returned from the expander to be processed by the evaluator, e.g., compile or interpret, that invoked the expander.

The value of the parameter eval-syntax-expanders-when actually determines the initial compile-time state set. The parameter is bound to a list of situations, which defaults to (compile load eval). When compiling a file, compile contributes “C” to the state set, load contributes “L,” visit contributes “V,” revisit contributes “R,” and eval contributes nothing. When not compiling a file, eval contributes “E” to the state set, and the other situations contribute nothing. There is no corresponding parameter for controlling the initial value of the run-time state set.

For RNRS top-level programs, eval-when is essentially ineffective. The entire program is treated as a single expression, so eval-when becomes a local eval-when for which only the eval situation has any relevance. As for any local eval-when form, the subforms are ignored if the eval situation is not present; otherwise, they are treated as if the eval-when wrapper were absent.

### eval-syntax-expanders-when

This parameter must be set to a list representing a set of eval-when situations, e.g., a list containing at most one occurrence of each of the symbols eval, compile, load, visit, and revisit. It is used to determine the evaluation time of syntax definitions, module forms, and import forms are expanded. (See the discussion of eval-when above.) The default value is (compile load eval), which causes compile-time information in a file to
be established when the file is loaded from source, when it is compiled via compile-file, and when a compiled version of the file is loaded via load or visit.

current-generate-id thread parameter

libraries: (chezscheme)

This parameter must be set to a procedure that accepts one argument, a symbol, and returns a fresh symbol. This procedure is called by the macro expander to get symbols to use for a top-level binding, as a record uid, or to identify a library compilation. The default procedure converts the symbol to a string and passes it to gensym.

For example, while expanding the following library, the current-generate-id procedure is called on the symbols a-lib, a-var, and a-var again.

(library (a-lib)
  (export a-var)
  (import (chezscheme))
  (define a-var 3)
  (define-syntax def
    (syntax-rules ()
      [(_) (define a-var 'other)])
  (def))

The procedure held by the current-generate-id parameter is called on a-lib to generate a symbol that identifies this particular library compilation, as opposed to the compilation of a different library named (a-lib). It is called on a-var the first time to select a distinct symbol to hold the value of the a-var definition, since a-var itself should not be defined directly at the top level. Finally, the current-generate-id procedure is called on a-var to select a name for the macro-introduced definition of a-var in the expansion of (def)—which turns out to be completely inaccessible since no reference is introduced by the same expansion step.

Setting the parameter to a particular, deterministic generator can cause symbols in the expansion of the library to be always the same. That determinism can be helpful if the expansion semantically matches an earlier expansion, so that uses of an earlier compilation remain compatible with the new one. Of course, reusing a symbol runs the risk of creating collisions that the macro and library system normally prevents via distinct symbols, and compiler optimizations may rely on the expectation of distinct symbols for distinct compilations. Configure current-generate-id at your own risk.

As a further example, suppose that the following two forms are compiled separately:

;; Compile this x.ss to x.so
(library (x)
  (export x)
  (import (chezscheme))
  (define x '(x)))
12.4. Compilation, Evaluation, and Loading

;; Compile this y.ss to y.so
(toplevel-program
  (import (chezscheme)
    (y))
  (printf "-s\n" x))

If x.ss is modified and recompiled, loading the new x.so and the old y.so will correctly report an error that the compiled y.so requires a different compilation instance that the one already loaded.

Suppose, however, that you’re willing to live dangerously to avoid recompiling y.ss by generating the same symbols for every compilation of x.ss. While compiling x.ss, you could set current-generate-id to the result of make-x-generator:

(define (make-x-generator)
  (let ([x-uid "gf91a5b83ujz3mogjdaiz-7-x"]
        [counter-ht (make-eq-hashtable)])
    (lambda (sym)
      (let* ([n (eq-hashtable-ref counter-ht sym 0)]
             [s ((if (gensym? sym) gensym->unique-string symbol->string) sym)]
             [g (gensym (symbol->string sym) (format "-a--a--a" x-uid s n))])
        (eq-hashtable-set! counter-ht sym (+ n 1))
        g))))

As long as the first and second compilations of x.ss use the result of make-x-generator, the first compilation of y.ss might work with the second compilation of x.ss, even if the change adds, removes, or reorders definitions of variables other than x.

Beware that if the variable x is originally defined as (define x 1), then the compilation of y.ss likely inlines the value 1 in place of its reference to the variable x, so changing x.ss will have no effect without recompiling y.ss. Similarly, if the change to x.ss deletes the definition of x or introduces a macro-generated definition of x before the direct definition, then the previously compiled y.ss is unlikely to refer to the correct definition of x in the new compilation of x.ss. Configure current-generate-id this way only in situations where the potential for unspecified failure is more tolerable than recompilation.

expand-omit-library-invocations thread parameter
libraries: (chezscheme)

This boolean-valued parameter determines whether library uses are recorded in macro expansion. Normally, when an expression expands to a reference to a library-defined identifier, the expansion is prefixed with a check to ensure that the exporting library is defined and invoked. If expand-omit-library-invocations is set to true, the prefix is omitted.

Setting expand-omit-library-invocations to true makes sense only when evaluating many small expressions in a context where all referenced libraries are known to be present and already invoked, and only when it’s worth saving the small overhead of representing and running the check.
12. System Operations

**compile-omit-concatenate-support**

thread parameter

libraries: (chezscheme)

This boolean-valued parameter determines whether code compiled to a file or port includes information needed to support *concatenate-object-files*. Omitting the information can provide minor space and load-time savings for small compiled objects.

12.5. Source Directories and Files

**source-directories**

global parameter

libraries: (chezscheme)

The value of **source-directories** must be a list of strings, each of which names a directory path. **source-directories** determines the set of directories searched for source or object files when a file is loaded via load, load-library, load-program, include, visit, or revisit, when a syntax error occurs, or when a source file is opened in the interactive inspector.

The default value is the list ".", which means source files will be found only in or relative to the current directory, unless named with an absolute path or a path that starts with ./ (or .\ under Windows) or ../ (or ..\ under Windows).

This parameter is never altered by the system, with one exception. The expander temporarily adds (via **parameterize**) the directory in which a library file resides to the front of the **source-directories** list when it compiles (when **compile-imported-libraries** is true) or loads the library from source, which it does only if the library is not already defined.

**with-source-path**

procedure

libraries: (chezscheme)

The procedure **with-source-path** searches through the current source-directories path, in order, for a file with the specified **name** and invokes **procedure** on the result. If no such file is found, an exception is raised with condition types &assertion and &who with **who** as who value.

If **name** is an absolute pathname or one beginning with ./ (or .\ under Windows) or ../ (or ..\ under Windows), or if the list of source directories contains only ".", the default, or "", which is equivalent to ".", no searching is performed and **name** is returned.

**who** must be a symbol, **name** must be a string, and **procedure** should accept one argument.

The following examples assumes that the file “pie” exists in the directory “../spam” but not in “../ham” or the current directory.

```scheme
(define find-file
  (lambda (fn)
    (with-source-path 'find-file fn values)))

(find-file "pie") ⇒ "pie"
```
(source-directories '("." "./ham"))
(find-file "pie") ⇒  exception in find-file: pie not found

(source-directories '("." "./spam"))
(find-file "pie") ⇒  "./spam/pie"

(source-directories '("." "./ham"))
(find-file "/pie") ⇒  "/pie"

(source-directories '("." "./ham"))
(find-file ".\./pie") ⇒  ".\./pie"

(source-directories '("." "./spam"))
(find-file ".\./pie") ⇒  ".\./ham/pie"

12.6. Compiler Controls

<table>
<thead>
<tr>
<th>optimize-level</th>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

This parameter can take on one of the four values 0, 1, 2, and 3.

In theory, this parameter controls the amount of optimization performed by the compiler. In practice, it does so only indirectly, and the only difference is between optimize level 3, at which the compiler generates “unsafe” code, and optimize levels 0–2, at which the compiler generates “safe” code. Safe code performs full type and bounds checking so that, for example, an attempt to apply a non-procedure, an attempt to take the car of a non-pair, or an attempt to reference beyond the end of a vector each result in an exception being raised. With unsafe code, the same situations may result in invalid memory references, corruption of the Scheme heap (which may cause seemingly unrelated problems later), system crashes, or other undesirable behaviors. Unsafe code is typically faster, but optimize-level 3 should be used with caution and only on sections of well-tested code that must run as quickly as possible.

While the compiler produces the same code for optimize levels 0–2, user-defined macro transformers can differentiate among the different levels if desired.

One way to use optimize levels is on a per-file basis, using eval-when to force the use of a particular optimize level at compile time. For example, placing:

(eval-when (compile) (optimize-level 3))

at the front of a file will cause all of the forms in the file to be compiled at optimize level 3 when the file is compiled (using compile-file) but does not affect the optimize level used when the file is loaded from source. Since compile-file parameterizes optimize-level (see parameterize), the above expression does not permanently alter the optimize level in the system in which the compile-file is performed.

The optimize level can also be set via the --optimize-level command-line option (Section 2.9). This option is particularly useful for running RNRS top-level programs at
optimize-level 3 via the --program command-line option, since eval-when is ineffective for RNRS top-level programs as described on page 385.

\[(\text{primitive \ variable})\] syntax
\[\#\text{variable} \text{ syntax}\]
\[(\text{primitive 2 \ variable})\] syntax
\[\#2\text{variable} \text{ syntax}\]
\[(\text{primitive 3 \ variable})\] syntax
\[\#3\text{variable} \text{ syntax}\]

returns: the primitive value for \textit{variable}

\textit{variable} must name a primitive procedure. The \text{primitive} syntactic form allows control over the optimize level at the granularity of individual primitive references, and it can be used to access the original value of a primitive, regardless of the lexical context or the current top-level binding for the variable originally bound to the primitive.

The expression \((\text{primitive \ variable})\) may be abbreviated as \#\text{variable}. The reader expands \# followed by an object into a \text{primitive} expression, much as it expands \textit{object} into a \textit{quote} expression.

If a 2 or 3 appears in the form or between the \# and \% in the abbreviated form, the compiler treats an application of the primitive as if it were compiled at the corresponding optimize level (see the optimize-level parameter). If no number appears in the form, an application of the primitive is treated as an optimize-level 3 application if the current optimize level is 3; otherwise, it is treated as an optimize-level 2 application.

\[(\#\text{car \ '(a b c)}) \Rightarrow \text{a}\]
\[(\text{let ([car cdr]} (\text{car \ '(a b c)}) \Rightarrow (\text{b c})\]
\[(\text{let ([car cdr]} (\#\text{car \ '(a b c)}) \Rightarrow \text{a}\]
\[(\text{begin (set! car cdr)} (\#\text{car \ '(a b c)}) \Rightarrow \text{a}\]

\text{debug-level} thread parameter

This parameter can take on one of the four values 0, 1, 2, and 3. It is used to tell the compiler how important the preservation of debugging information is, with 0 being least important and 3 being most important. The default value is 1. As of Version 9.0, it is used solely to determine whether an error-causing call encountered in nontail position is treated as if it were in tail position (thus causing the caller’s frame not to appear in a stack backtrace); this occurs at debug levels below 2.

\text{generate-interrupt-trap} thread parameter

To support interrupts, including keyboard, timer, and collect request interrupts, the compiler inserts a short sequence of instructions at the entry to each nonleaf procedure (Section 12.2). This small overhead may be eliminated by setting \text{generate-interrupt-trap} to \#f. The default value of this parameter is \text{#t}. 
It is rarely a good idea to compile code without interrupt trap generation, since a tight loop in the generated code may completely prevent interrupts from being serviced, including the collect request interrupt that causes garbage collections to occur automatically. Disabling trap generation may be useful, however, for routines that act simply as “wrappers” for other routines for which code is presumably generated with interrupt trap generation enabled. It may also be useful for short performance-critical routines with embedded loops or recursions that are known to be short running and that make no other calls.

**compile-interpret-simple**  
libraries: (chezscheme)

At all optimize levels, when the value of `compile-interpret-simple` is set to a true value (the default), `compile` interprets simple expressions. A simple expression is one that creates no procedures. This can save a significant amount of time over the course of many calls to `compile` or `eval` (with `current-eval` set to `compile`, its default value). When set to false, `compile` compiles all expressions.

**generate-inspector-information**  
libraries: (chezscheme)

When this parameter is set to a true value (the default), information about the source and contents of procedures and continuations is generated during compilation and retained in tables associated with each code segment. This information allows the inspector to provide more complete information, at the expense of using more memory and producing larger object files (via `compile-file`). Although compilation and loading may be slower when inspector information is generated, the speed of the compiled code is not affected. If this parameter is changed during the compilation of a file, the original value will be restored. For example, if:

```
(eval-when (compile) (generate-inspector-information #f))
```

is included in a file, generation of inspector information will be disabled only for the remainder of that particular file.

**generate-procedure-source-information**  
libraries: (chezscheme)

When `generate-inspector-information` is set to `#f` and this parameter is set to `#t`, then a source location is preserved for a procedure, even though other inspector information is not preserved. Source information provides a small amount of debugging support at a much lower cost in memory and object-file size than full inspector information. If this parameter is changed during the compilation of a file, the original value will be restored.
enable-cross-library-optimization thread parameter
libraries: (chezscheme)

This parameter controls whether information is included with the object code for a compiled library to enable propagation of constants and inlining of procedures defined in the library into dependent libraries. When set to #t (the default), this information is included; when set to #f, the information is not included. Setting the parameter to #f potentially reduces the sizes of the resulting object files and the exposure of near-source information via the object file.

enable-arithmetic-left-associative thread parameter
libraries: (chezscheme)

This parameter controls whether the compiler is constrained to implement +, fx+, fl+, cfl+, *, fx*, fl*, and cfl* as left-associative operations when given more than two arguments. The default is #f.

enable-error-source-expression thread parameter
libraries: (chezscheme)

This parameter controls whether the compiler can convert erroneous expressions into a call to an error function that shows the expression as an S-expression. The default is #t.

enable-unsafe-application thread parameter
libraries: (chezscheme)

This parameter controls whether application forms are compiled as unsafe (i.e., no check whether the target is a procedure), even when the value of optimize-level is less than 3. The default is #f.

enable-unsafe-variable-reference thread parameter
libraries: (chezscheme)

This parameter controls whether references to letrec-bound variables are compiled unsafe (i.e., no check whether the variable has a value), even when the value of optimize-level is less than 3. The default is #f.

generate-wpo-files thread parameter
libraries: (chezscheme)

When this parameter is set to #t (the default is #f), compile-file, compile-library, compile-program, and compile-script produce whole-program optimization (wpo) files for use by compile-whole-program. The name of the wpo file is derived from the output-file name by replacing the object-file extension (normally .so) with .wpo, or adding the extension .wpo if the object filename has no extension or has the extension .wpo.
12.6. Compiler Controls

<table>
<thead>
<tr>
<th>compile-file-message</th>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

When this parameter is set to true, the default, compile-file, compile-library, compile-program, and compile-script print a message of the form:

**compiling** *input-path* with output to *output-path*

When the parameter is set to #f, the message is not printed.

<table>
<thead>
<tr>
<th>run-cp0</th>
<th>thread parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>cp0-effort-limit</td>
<td>thread parameter</td>
</tr>
<tr>
<td>cp0-score-limit</td>
<td>thread parameter</td>
</tr>
<tr>
<td>cp0-outer-unroll-limit</td>
<td>thread parameter</td>
</tr>
<tr>
<td>libraries: (chezscheme)</td>
<td></td>
</tr>
</tbody>
</table>

These parameters control the operation of cp0 plus ctypes, source optimization passes that run after macro expansion and prior to most other compiler passes.

cp0 performs procedure inlining, in which the code of one procedure is inlined at points where it is called by other procedures, as well as copy propagation, constant folding, useless code elimination, and several related optimizations. The algorithm used by the optimizer is described in detail in the paper “Fast and effective procedure inlining” [31].

ctypes performs additional optimizations based on type information about primitives, such as the fact that + always returns a number; since it primarily removes unnecessary run-time checks, ctypes primarily benefits compilation in safe mode. The ctypes pass can be independently disabled through the enable-type-recovery parameter.

When cp0 is enabled, the programmer can count on the compiler to fold constants, eliminate unnecessary let bindings, and eliminate unnecessary and inaccessible code. This is particularly useful when writing macros, since the programmer can usually handle only the general case and let the compiler simplify the code when possible. For example, the programmer can define case as follows:

```scheme
(define-syntax case
  (syntax-rules ()
    [(_ e [(k ...) a1 a2 ...] ...) [else b1 b2 ...])
    (let ([t e])
      (cond
        [(memv t '(k ...)) a1 a2 ...]
        ...
        [else b1 b2 ...]])
    [(_ e [(k ...) a1 a2 ...] ...) [else b1 b2 ...])]
    [(_ e [(k ...) a1 a2 ...] ...) [else b1 b2 ...])]
    (let ([t e])
      (cond
        [(memv t '(k ...)) a1 a2 ...]
        ...
        [else b1 b2 ...]])
    )))

and count on the introduce let expression to be eliminated if e turns out to be an unas-
signed variable, and count on the entire case expression to be folded if e turns out to be a constant.

It is possible to see what cp0 plus cptypes does with an expression via the procedure expand/optimize, which expands its argument and passes the result through cp0 and cptypes, as illustrated by the following transcript.

```scheme
> (print-gensym #f)
> (expand/optimize '(lambda (x)
                   (case x [(a) 1] [(b c) 2] [(d) 3] [else 4])))
(lambda (x)
  (if (#2%member x '(a)) 1
     (if (#2%member x '(b c)) 2 (if (#2%member x '(d)) 3 4))))
```

```scheme
> (expand/optimize '+ (let ([f (lambda (x)
                           (case x [(a) 1] [(b c) 2] [(d) 3] [else 4])])
                         (f 'b))
                         15))
17
```

In the first example, the let expression produced by case is eliminated, and in the second, the entire expression is optimized down to the constant 17. Although not shown by expand/optimize, the member calls in the output code for the first example will be replaced by calls to the less expensive eq? by a later pass of the compiler. Additional examples are given in the description of expand/optimize.

The value of run-cp0 must be a procedure. Whenever the compiler is invoked on a Scheme form, the value p of this parameter is called to determine whether and how cp0 and cptypes are run. p receives two arguments: cp0, the entry point into the cp0 plus cptypes passes, and x, the form being compiled. The default value of run-cp0 simply invokes cp0 on x, then cp0 again on the result. The second run is useful in some cases because the first run may not eliminate bindings for certain variables that appear to be referenced but are not actually referenced after inlining. The marginal benefit of the second run is usually minimal, but so is the cost.

Interesting variants include

```
(run-cp0 (lambda (cp0 x) x))
```

which bypasses (disables) cp0, and

```
(run-cp0 (lambda (cp0 x) (cp0 x))
```

which runs cp0 just once.

The value of cp0-effort-limit determines the maximum amount of effort spent on each inlining attempt. The time spent optimizing a program is a linear function of this limit and the number of calls in the program’s source, so small values for this parameter enforce a tighter bound on compile time. When set to zero, inlining is disabled except when the
name of a procedure is referenced only once. The value of \texttt{cp0-score-limit} determines the maximum amount of code produced per inlining attempt. Small values for this parameter limit the amount of overall code expansion. These parameters must be set to nonnegative fixnum values.

The parameter \texttt{cp0-outer-unroll-limit} controls the amount of inlining performed by the optimizer for recursive procedures. With the parameter’s value set to the default value of 0, recursive procedures are not inlined. A nonzero value for the outer unroll limit allows calls external to a recursive procedure to be inlined. For example, the expression

\begin{verbatim}
(letrec ([fact (lambda (x) (if (zero? x) 1 (* x (fact (- x 1)))))]
         (fact 10))
\end{verbatim}

would be left unchanged with the outer unroll limit set to zero, but would be converted into

\begin{verbatim}
(letrec ([fact (lambda (x) (if (zero? x) 1 (* x (fact (- x 1)))))]
         (* 10 (fact 9)))
\end{verbatim}

with the outer unroll limit set to one.

Interesting effects can be had by varying several of these parameters at once. For example, setting the effort and outer unroll limits to large values and the score limit to 1 has the effect of inlining even complex recursive procedures whose values turn out to be constant at compile time without risking any code expansion. For example,

\begin{verbatim}
(letrec ([fact (lambda (x) (if (zero? x) 1 (* x (fact (- x 1)))))]
         (fact 10))
\end{verbatim}

would be reduced to 3628800, but

\begin{verbatim}
(letrec ([fact (lambda (x) (if (zero? x) 1 (* x (fact (- x 1)))))]
         (fact z))
\end{verbatim}

would be left unchanged, although the optimizer may take a while to reach this decision if the effort and outer unroll limits are large.

\begin{verbatim}
enable-type-recovery thread parameter
libraries: (chezscheme)
\end{verbatim}

A parameter that controls whether the compiler attempts to optimize programs by performing a pass similar to type inference, which can avoid more checks and statically resolve more predicates than \texttt{cp0} by itself, but at the cost of extra compile time. The default is \texttt{#t}.

\begin{verbatim}
commonization-level thread parameter
libraries: (chezscheme)
\end{verbatim}

After running the main source optimization pass (\texttt{cp0}) for the last time, the compiler optionally runs a \textit{commonization} pass. The pass commonizes the code for lambda expressions
that have identical structure by abstracting differences at certain leaves of the program, namely constants, references to unassigned variables, and references to primitives. The parameter `commonization-level` controls whether commonization is run and, if so, how aggressive it is. Its value must be a nonnegative exact integer ranging from 0 through 9. When the parameter is set to 0, the default, commonization is not run. Otherwise, higher values result in more commonization.

Commonization can undo some of the effects of cp0's inlining, can add run-time overhead, and can complicate debugging, particularly at higher commonization levels, which is why it is disabled by default. On the other hand, for macros or other meta programs that can generate large, mostly similar lambda expressions, enabling commonization can result in significant savings in object-code size and even reduce run-time overhead by making more efficient use of instruction caches.

```
undefined-variable-warnings
libraries: (chezscheme)
```

When `undefined-variable-warnings` is set to `#t`, the compiler issues a warning message whenever it cannot determine that a variable bound by `letrec`, `letrec*`, or an internal definition will not be referenced before it is defined. The default value is `#f`.

Regardless of the setting of this parameter, the compiler inserts code to check for the error, except at optimize level 3. The check is fairly inexpensive and does not typically inhibit inlining or other optimizations. In code that must be carefully tuned, however, it is sometimes useful to reorder bindings or make other changes to eliminate the checks. Enabling undefined-variable warnings can facilitate this process.

The checks are also visible in the output of `expand/optimize`.

```
ex pand-output
expand/optimize-output
libraries: (chezscheme)
```

The parameters `expand-output` and `expand/optimize-output` can be used to request that the compiler and interpreter print expander and source-optimizer output produced during the compilation or interpretation process. Each parameter must be set to either `#f` (the default) or a textual output port.

When `expand-output` is set to a textual output port, the output of the expander is printed to the port as a side effect of running `compile`, `interpret`, or any of the file compiling primitives, e.g., `compile-file` or `compile-library`. Similarly, when `expand/optimize-output` is set to a textual output port, the output of the source optimizer is printed.

See also `expand` (page 379) and `expand-optimize` (page 380), which can be used to run the expander or the expander and source optimizer directly on an individual form.
(pariah expr₁ expr₂ ...)  syntax
returns: the values of the last subexpression
libraries: (chezscheme)

A pariah expression is just like a begin expression except that it informs the compiler that the code is expected to be executed infrequently. The compiler uses this information to optimize code layout, register assignments, and other aspects of the generated code. The pariah form can be used in performance-critical code to mark the branches of a conditional (e.g., if, cond, or case) that are less likely to be executed than the others.

12.7. Profiling

ChezScheme supports two forms of profiling: source profiling and block profiling. With source profiling enabled, the compiler instruments the code it produces to count the number of times each source-code expression is executed. This information can be displayed in HTML format, or it can be packaged in a list or source table for arbitrary user-defined processing. It can also be dumped to a file to be loaded subsequently into the compiler’s database of profile information for use in source-level optimizations, such as reordering the clauses of a case or exclusive-cond form. In connection with coverage-information (covin) files generated by the compiler when generate-covin-files is #t, profile information can also be used to gauge coverage of a source-code base by a set of tests.

The association between source-code expressions and profile counts is usually established via annotations produced by the reader and present in the input to the expander (Section [11.11]). It is also possible to explicitly identify source positions to be assigned profile counts via profile expressions. A profile expression has one subform, a source object, and returns an unspecified value. Its only effect is to cause the number of times the expression is executed to be accounted to the source object.

In cases where source positions explicitly identified by profile forms are the only ones whose execution counts should be tracked, the parameter generate-profile-forms can be set to #f to inhibit the expander’s implicit generation of profile forms for all annotated source expressions. It is also possible to obtain finer control over implicit generation of profile forms by marking which annotations should and should not be used for profiling (Section [11.11]).

With block profiling enabled, the compiler similarly instruments the code it produces to count the number of times each “basic block” in the code it produces is executed. Basic blocks are the building blocks of the code produced by many compilers, including Chez Scheme’s compiler, and are sequences of straight-line code entered only at the top and exited only at the bottom. Counting the number of times each basic block is executed is equivalent to counting the number of times each instruction is executed, but more efficient. Block-profile information cannot be viewed, but it can be dumped to a file to be loaded subsequently into the compiler’s database of profile information for use in block- and instruction-level optimizations. These optimizations include reordering blocks to push less frequently used sequences of code out-of-line, so they will not occupy space in the in-
struction cache, and giving registers to variables that are used in more frequently executed instructions.

Source profiling involves at least the following steps:

- compile the code with source profiling enabled,
- run the compiled code to generate source-profile information, and
- dump the profile information.

Source profiling is enabled by setting the parameter `compile-profile` to the symbol `source` or to the boolean value `#t`. The profile information can be dumped via:

- `profile-dump-html` in HTML format to allow the programmer to visualize how often each expression is executed using a color-coding system that makes it easy to spot “hot spots,”
- `profile-dump-list` in a form suitable for user-defined post-processing,
- `profile-dump` in a form suitable for off-line processing by one of the methods above or by some custom means, or
- `profile-dump-data` in a form suitable for loading into the compiler’s database.

If the information is intended to be fed back into the compiler for optimization, the following additional steps are required, either in the same or a different Scheme process:

- load the profile information into the compiler’s profile database, and
- recompile the code.

Profile information dumped by `profile-dump-data` is loaded into the compiler’s profile database via `profile-load-data`. Profiling information is not available to the compiler unless it is explicitly dumped via `profile-dump-data` and loaded via `profile-load-data`.

When block-profile information is to be used for optimization, the steps are similar:

- compile the code with block profiling enabled,
- run the code to generate block-profile information,
- dump the profile information,
- load the profile information, and
- recompile the code.

Block profiling is enabled by setting the parameter `compile-profile` to the symbol `block` or to the boolean value `#t`. The profile information must be dumped via `profile-dump-data` and loaded via `profile-load-data`. As with source profile information, block profile information can be loaded in the same or in a different Scheme process as the one that dumped the information.

For block optimization, the code to be recompiled must be identical. In general, this means the files involved must not have been modified, and nothing else can change that indirectly affects the code produced by the compiler, e.g., settings for compiler parameters such as `optimize-level` or the contents of configuration files read by macros at compile
12.7. Profiling

time. Otherwise, the set of blocks or the instructions within them might be different, in which case the block profile information will not line up properly and the compiler will raise an exception.

For the same reason, when both source profiling and block profiling information is to be used for optimization, the source information must be gathered first and loaded before both the first and second compilation runs involved in block profiling. That is, the following steps must be used:

1. compile the code with source profiling enabled,
2. run the code to generate source-profile information,
3. dump the source-profile information,
4. load the source-profile information,
5. recompile the code with block profiling enabled,
6. run the code to generate block-profile information,
7. dump the block-profile information,
8. load the source- and block-profile information, and
9. recompile the code.

The numbers labeling each step indicate both the order of the steps and those that must be performed in the same Scheme process. (All of the steps can be performed in the same Scheme process, if desired.)

Both source and block profiling are disabled when compile-profile is set to #f, its default value.

The following example highlights the use of source profiling for identifying hot spots in the code. Let’s assume that the file /tmp/fatfib/fatfib.ss contains the following source code.

```
(define fat+
  (lambda (x y)
    (if (zero? y)
      x
      (fat+ (1+ x) (1- y))))
  )

(define fatfib
  (lambda (x)
    (if (< x 2)
      1
      (fat+ (fatfib (1- x)) (fatfib (1- (1- x)))))))
```

We can load fatfib.ss with profiling enabled as follows.

```
(parameterize ([compile-profile 'source])
  (load "~/tmp/fatfib/fatfib.ss")
)
```

We then run the application as usual.

```
(fatfib 20) ⇒ 10946
```
After the run (or multiple runs), we dump the profile information as a set of html files using `profile-dump-html`.

This creates a file named `profile.html` containing a summary of the profile information gathered during the run. If we view this file in a browser, we should see something like the following.

![Profile Output](image)

The most frequently executed code is highlighted in colors closer to red in the visible spectrum, while the least frequently executed code is highlighted in colors closer to violet. Each of the entries in the lists of files and hot spots are links into additional generated files, one per source file (provided `profile-dump-html` was able to locate an unmodified copy of the source file). In this case, there is only one, `fatfib.ss.html`. If we move to that file, we should see something like this:
As in the summary, the code is color-coded according to frequency of execution. Hovering over a color-coded section of code should cause a pop-up box to appear with the starting position and count of the source expression. If a portion of source code is not color-coded or is identified via the starting position as having inherited its color from some enclosing expression, it may have been recognized as dead code by the compiler or garbage collector and discarded, or the expander might not have been able to track it through the macro-expansion process.

`profile-dump` and `profile-dump-list` may be used to generate a list of profile entries, which may then be analyzed manually or via a custom profile-viewing application.

```
1  (define fat' [lambda (x y)
2    (if (zero? y)
3      x
4      (fat' (+ x) (- y)))])
6  (define fatfib
7    [lambda (x)
9      (if (< x 2)
10      (fat' (fatfib (- x)) (fatfib (- 1 (- x)))))])
```

When this parameter is set to the symbol `source` or the boolean value `#t`, the compiler instruments the code it generates with instructions that count the number of times each section of source code is executed. When set to the symbol `block`, the compiler similarly instruments the code it generates with instructions that count the number of times each block of code is executed. When set to `#f` (the default), the compiler does not insert these instructions.

The general description of profiling above describes how the source and block profile information can be viewed or used for optimization.

The code generated when `compile-profile` is non-false is larger and less efficient, so this parameter should be set only when profile information is needed.

The profile counters for code compiled when profile instrumentation is enabled are retained indefinitely, even if the code with which they are associated is reclaimed by the garbage collector. This results in more complete and accurate profile data but can lead
to space leaks in programs that dynamically generate or load code. Such programs can avoid the potential space leak by releasing the counters explicitly via the procedure \texttt{profile-release-counters}.

\texttt{generate-covin-files} \hspace{1cm} \textbf{thread parameter} \hspace{1cm} \textbf{libraries:} (chezscheme)

When this parameter is set to \#t, the compiler generates “coverage-information” (covin) files that can be used in connection with profile information to measure coverage of a source-code base by a set of tests. One covin file is created for each object file, with the object-file extension replaced by the extension \texttt{.covin}. Each covin file contains the printed representation of a source table (Section 11.12), compressed using the compression format and level specified by \texttt{compress-format} and \texttt{compress-level}. This information can be read via \texttt{get-source-table!} and used as a universe of source expressions to identify source expressions that are not evaluated during the running of a set of tests.

\texttt{(profile source-object)} \hspace{1cm} \textbf{syntax} \hspace{1cm} \textbf{returns:} unspecified \hspace{1cm} \textbf{libraries:} (chezscheme)

A \texttt{profile} form has the effect of accounting to the source position identified by \texttt{source-object} the number of times the \texttt{profile} form is executed. Profile forms are generated implicitly by the expander for source expressions in annotated input, e.g., input read by the compiler or interpreter from a Scheme source file, so this form is typically useful only when unannotated source code is produced by the front end for some language that targets Scheme.

\texttt{(generate-profile-forms)} \hspace{1cm} \textbf{thread parameter} \hspace{1cm} \textbf{libraries:} (chezscheme)

When this parameter is set to \#t, the default, the expander implicitly introduces \texttt{profile} forms for each annotated input expression, unless the annotation has not been marked for use in profiling (Section 11.11). It can be set to \#f to inhibit the expander’s implicit generation of \texttt{profile} forms, typically when explicit \texttt{profile} forms are already present for all source positions that should be profiled.

\texttt{(profile-clear)} \hspace{1cm} \textbf{procedure} \hspace{1cm} \textbf{returns:} unspecified \hspace{1cm} \textbf{libraries:} (chezscheme)

Calling this procedure causes profile information to be cleared, i.e., the counts associated with each section of code are set to zero.
12.7. Profiling

(profle-release-counters)  procedure
returns: unspecified
libraries: (chezscheme)

Calling this procedure causes profile information associated with reclaimed code objects to be dropped.

(profle-dump)  procedure
returns: a list of pairs of source-object and count
libraries: (chezscheme)

This procedure produces a dump of all profile information gathered since startup or the last call to profile-clear. It returns a list of pairs, where the car of each pair is a source object (Section 11.11) and the cdr is an exact nonnegative integer count.

The list might contain more than one entry per source object due to macro expansion and procedure inlining, and it might contain more than one (non-eq) source object per file and source position due to separate compilation. In such cases, the counts are not overlapping and can be summed together to obtain the full count.

The advantage of profile-dump over profile-dump-list is that profile-dump performs only minimal processing and preserves complete source objects, including their embedded source-file descriptors. It might be used, for example, to dump profile information to a fasl file on one machine for subsequent processing on another.

with-profile-tracker can be used to obtain the same set of counts as a source table.

(with-profile-tracker thunk)  procedure
(with-profile-tracker preserve-existing? thunk)  procedure
returns: a source table and the values returned by thunk
libraries: (chezscheme)

thunk must be a procedure and should accept zero arguments. It may return any number of values.

with-profile-tracker invokes thunk without arguments. If thunk returns n values $x_1, x_2, \ldots, x_n$, with-profile-tracker returns $n + 1$ values $st, x_1, x_2, \ldots, x_n$, where $st$ is a source table associating source objects with profile counts. If preserve-existing? is absent or #f, each count represents the number of times the source expression represented by the associated source object is evaluated during the invocation of thunk. Otherwise, each count represents the number of times the source expression represented by the associated source object is evaluated before or during the invocation of thunk.

Profile data otherwise cleared by a call to profile-clear or profile-release-counters during the invocation of thunk is included in the resulting table. That is, invoking these procedures while thunk is running has no effect on the resulting counts. On the other hand, profile data cleared before with-profile-tracker is invoked is not included in the resulting table.
The idiom \texttt{(with-profile-tracker \#t values)} can be used to obtain the current set of profile counts as a source table.

\begin{verbatim}
(source-table-dump source-table) procedure
returns: a list of pairs of source objects and their associated values in source-table
libraries: (chezscheme)
\end{verbatim}

This procedure can be used to convert a source-table produced by \texttt{with-profile-tracker} or some other mechanism into the form returned by \texttt{profile-dump} for use as an argument to \texttt{profile-dump-html}, \texttt{profile-dump-list}, or \texttt{profile-dump-data}.

\begin{verbatim}
(profile-dump-html) procedure
(profile-dump-html prefix) procedure
(profile-dump-html prefix dump) procedure
returns: unspecified
libraries: (chezscheme)
\end{verbatim}

This procedure produces one or more HTML files, including profile.html, which contains color-coded summary information, and one file \texttt{source.html} for each source file \texttt{source} containing a color-coded copy of the source code, as described in the lead-in to this section. If \texttt{prefix} is specified, it must be a string and is prepended to the names of the generated HTML files. For example, if \texttt{prefix} is \texttt{/tmp/}, the generated files are placed in the directory /tmp. The raw profile information is obtained from \texttt{dump}, which defaults to the value returned by \texttt{profile-dump}.

\begin{verbatim}
(profile-palette) thread parameter
libraries: (chezscheme)
\end{verbatim}

This value of this parameter must be a nonempty vector of at least three pairs. The car of each pair is a background color and the cdr is a foreground (text) color. Each color must be a string, and each string should contain an HTML cascading style sheet (CSS) color specifier. The first pair is used for unprofiled code, and the second is used for unexecuted profiled code. The third is used for code that is executed least frequently, the fourth for code executed next-least frequently, and so on, with the last being used for code that is executed most frequently. Programmers may wish to supply their own palette to enhance visibility or to change the number of colors used.

By default, a black background is used for unprofiled code, and a gray background is used for unexecuted profiled code. Background colors ranging from purple to red are used for executed profiled code, depending on frequency of execution, with red for the most frequently executed code.
12.7. Profiling

```scheme
(profile-palette) ⇒
  #(("#111111" . "white") ("#607D8B" . "white")
   ("#9C27B0" . "black") ("#673AB7" . "white")
   ("#3F51B5" . "white") ("#2196F3" . "black")
   ("#00BCD4" . "black") ("#4CAF50" . "black")
   ("#CDDC39" . "black") ("#FFEB3B" . "black")
   ("#FFC107" . "black") ("#FF9800" . "black")
   ("#F44336" . "white"))

(profile-palette)
  ; set palette with rainbow colors and black text
  ; for all but unprofiled or unexecuted code
  ’#(("#000000" . "white") ; black
     ("#666666" . "white") ; gray
     ("#800080" . "black") ; violet
     ("#6600FF" . "black") ; indigo
     ("#0000FF" . "black") ; blue
     ("#00FF00" . "black") ; green
     ("#FFFF00" . "black") ; yellow
     ("#FF7F00" . "black") ; orange
     ("#FF0000" . "black"))) ; red
```

### (profile-line-number-color)

thread parameter

libraries: (chezscheme)

This value of this parameter must be a string or #f. If it is a string, the string should contain an HTML cascading style sheet (CSS) color specifier. If the parameter is set to a string, profile-dump-html includes line numbers in its html rendering of each source file, using the specified color. If the parameter is set to #f, no line numbers are included.

### (profile-dump-list)

procedure

returns: a list of profile entries (see below)

libraries: (chezscheme)

This procedure produces a dump of all profile information present in dump, which defaults to the value returned by profile-dump. It returns a list of entries, each of which is itself a list containing the following elements identifying one block of code and how many times it has been executed.

- execution count
- pathname
- beginning file position in characters (inclusive)
- ending file position in characters (exclusive)
- line number of beginning file position
- character position of beginning file position
profile-dump-list may be unable to locate an unmodified copy of the file in the current source directories or at the absolute address, if an absolute address was used when the file was compiled or loaded. If this happens, the line number and character position of the beginning file position are #f and the pathname is the pathname originally used. A warning is also issued (an exception with condition type &warning is raised) unless the warn? argument is provided and is false.

Otherwise, the pathname is the path to an unmodified copy of the source and the line and character positions are set to exact nonnegative integers.

In either case, the execution count, beginning file position, and ending file position are all exact nonnegative integers, and the pathname is a string.

For source positions in files that cannot be found, the list might contain more than one entry per position due to macro expansion, procedure inlining, and separate compilation. In such cases, the counts are not overlapping and can be summed together to obtain the full count.

The information returned by profile-dump-list can be used to implement a custom viewer or used as input for offline analysis of profile information.

The advantage of profile-dump-list over profile-dump is that it attempts to determine the line number and character position for each source point and, if successful, aggregates multiple counts for the source point into a single entry.

(profile-dump-data path)  procedure
(profile-dump-data path dump)  procedure

returns: unspecified
libraries: (chezscheme)

path must be a string.

This procedure writes, in a machine-readable form consumable by profile-load-data, profile counts represented by dump to the file named by path, replacing the file if it already exists. dump defaults to the value returned by profile-dump.

(profile-load-data path ...)  procedure

returns: unspecified
libraries: (chezscheme)

Each path must be a string.

This procedure reads profile information from the files named by path ... and stores it in the compiler’s internal database of profile information. The contents of the files must have been created originally by profile-dump-data using the same version of Chez Scheme.

The database stores a weight for each source expression or block rather than the actual count. When a single file is loaded into the database, the weight is the proportion of the actual count over the maximum count for all expressions or blocks represented in the file. When more than one file is loaded, either by one or multiple calls to profile-load-data, the weights are averaged.
(profile-query-weight obj)  
procedure
returns: obj’s profile weight, or #f if obj is not in the database
libraries: (chezscheme)

The compiler’s profile database maps source objects (Section 11.11) to weights. If obj is a source object, the profile-query-weight returns the weight associated with the source object or #f if the database does not have a weight recorded for the source object. obj can also be an annotation or syntax object, in which case profile-query-weight first extracts the source object, if any, using syntax->annotation and annotation-source, returning #f if no source-object is found.

A weight is a flonum in the range 0.0 to 1.0, inclusive, and denotes the ratio of the actual count to the maximum count as described in the description of profile-load-data.

profile-query-weight can be used by a macro to determine the relative frequency with which its subexpressions were executed in the run or runs that generated the information in the database. This information can be used to guide the generation of code that is likely to be more efficient. For example, the case macro uses profile information, when available, to order the clauses so that those whose keys matched more frequently are tested before those whose keys matched less frequently.

(profile-clear-database)  
procedure
returns: unspecified
libraries: (chezscheme)

This procedure clears the compiler’s profile database. It has no impact on the counts associated with individual sections of instrumented code; profile-clear can be used to reset those counts.

12.8. Waiter Customization

(new-cafe)  
procedure
(new-cafe eval-proc)  
procedure
returns: see below
libraries: (chezscheme)

Chez Scheme interacts with the user through a waiter, or read-eval-print loop (REPL). The waiter operates within a context called a café. When the system starts up, the user is placed in a café and given a waiter. new-cafe opens a new Scheme café, stacked on top of the old one. In addition to starting the waiter, new-cafe sets up the café’s reset and exit handlers (see reset-handler and exit-handler). Exiting a café resumes the continuation of the call to new-cafe that created the café. Exiting from the initial café leaves Scheme altogether. A café may be exited from either by an explicit call to exit or by receipt of end-of-file (“control-D” on Unix systems) in response to the waiter’s prompt. In the former case, any values passed to exit are returned from new-cafe.
If the optional eval-proc argument is specified, eval-proc is used to evaluate forms entered from the console. Otherwise, the value of the parameter current-eval is used. eval-proc must accept one argument, the expression to evaluate.

Interesting values for eval-proc include expand, which causes the macro expanded value of each expression entered to be printed and (lambda (x) x), which simply causes each expression entered to be printed. An arbitrary procedure of one argument may be used to facilitate testing of a program on a series of input values.

> (new-cafe (lambda (x) x))
>> 3
3
>> (a . (b . (c . ())))
(a b c)

(define sum
  (lambda (ls)
    (if (null? ls)
        0
        (+ (car ls) (sum (cdr ls))))))
> (new-cafe sum)
>> (1 2 3)
6

The default waiter reader (see waiter-prompt-and-read) displays the current waiter prompt (see waiter-prompt-string) to the current value of console-output-port and reads from the current value of console-input-port. The default waiter printer (see waiter-write) sends output to the current value of console-output-port. These parameters, along with current-eval, can be modified to change the behavior of the waiter.

waiter-prompt-string  thread parameter
libraries: (chezscheme)

The value of waiter-prompt-string must be a string. It is used by the default waiter prompter (see the parameter waiter-prompt-and-read) to print a prompt. Nested cafés are marked by repeating the prompt string once for each nesting level.

> (waiter-prompt-string)
">
> (waiter-prompt-string "\%")
\% (waiter-prompt-string)
"\%"
\% (new-cafe)
\%\% (waiter-prompt-string)
"\%"
waiter-prompt-and-read  
thread parameter  
libraries: (chezscheme)

waiter-prompt-and-read must be set to a procedure. It is used by the waiter to print a prompt and read an expression. The value of waiter-prompt-and-read is called by the waiter with a positive integer that indicates the café nesting level. It should return an expression to be evaluated by the current evaluator (see new-cafe and current-eval).

(default-prompt-and-read level)  
procedure  
libraries: (chezscheme)

level must be a positive integer indicating the café nesting level as described above.

This procedure is the default value of the waiter-prompt-and-read parameter whenever the expression editor (Section 2.2, Chapter 14) is not enabled. It might be defined as follows.

(define default-prompt-and-read  
(lambda (n)  
  (unless (and (integer? n) (>= n 0))  
    (assertion-violationf 'default-prompt-and-read  
                        "-s is not a nonnegative integer"  
                        n))  
  (let ([prompt (waiter-prompt-string)])  
    (unless (string=? prompt "")  
      (do ([n n (- n 1)])  
        ((= n 0)  
          (write-char \space (console-output-port))  
          (flush-output-port (console-output-port)))  
        (display prompt (console-output-port))))  
  (let ([x (read (console-input-port))])  
    (when (and (eof-object? x) (not (string=? prompt "")))  
      (newline (console-output-port))  
      (flush-output-port (console-output-port)))  
    x))))

waiter-write  
thread parameter  
libraries: (chezscheme)

The value of waiter-write must be a procedure. The waiter uses the value of waiter-write to print the results of each expression read and evaluated by the waiter. The following example installs a procedure equivalent to the default waiter-write:

(waiter-write  
(lambda (x)  
  (unless (eq? x (void))  
    (pretty-print x (console-output-port)))  
  (flush-output-port (console-output-port))))
(reset) procedure
returns: does not return
libraries: (chezscheme)

reset invokes the current reset handler (see reset-handler) without arguments.

reset-handler thread parameter
libraries: (chezscheme)

The value of this parameter must be a procedure and should accept zero arguments. The current reset handler is called by reset. The default reset handler resets to the current café.

(exit obj ...) procedure
returns: does not return
libraries: (chezscheme)

exit invokes the current exit handler (see exit-handler), passing along its arguments, if any.

exit-handler thread parameter
libraries: (chezscheme)

The value of this parameter must be a procedure and should accept any number of arguments. The current exit handler is called by exit.

The default exit handler exits from the current café, returning its arguments as the values of the call to new-cafe that created the current café. If the current café is the original café, or if exit is called from a script, exit exits from Scheme. In this case, the exit code for the Scheme process is 0 if no arguments were supplied or if the first argument is void, the value of the first argument cast to a C int if it is an exact integer of the host machine’s bit width, and 1 otherwise.

(abort) procedure
(abort obj) procedure
returns: does not return
libraries: (chezscheme)

abort invokes the current abort handler (see abort-handler), passing along its argument, if any.

abort-handler thread parameter
libraries: (chezscheme)

The value of this parameter must be a procedure and should accept either zero arguments or one argument. The current abort handler is called by abort.
The default abort handler exits the Scheme process. The exit code for the Scheme process is -1 if no arguments were supplied, 0 if the first argument is void, the value of the first argument if it is a 32-bit exact integer, and -1 otherwise.

The value of scheme-start is a procedure that determines the system’s action upon start-up. The procedure receives zero or more arguments, which are strings representing the file names (or command-line arguments not recognized by the Scheme executable) after given on the command line. The default value first loads the files named by the arguments, then starts up the initial café:

```
(lambda fns
 (for-each load fns)
 (new-cafe))
```

scheme-start may be altered to start up an application or to perform customization prior to normal system start-up.

To have any effect, this parameter must be set within a boot file. (See Chapter 2)

The value of scheme-script is a procedure that determines the system’s action upon start-up, when the --script option is used. The procedure receives one or more arguments. The first is a string identifying the script filename and the remainder are strings representing the remaining file names (or command-line arguments not recognized by the Scheme executable) given on the command line. The default value of this parameter is a procedure that sets the command-line and command-line-arguments parameters, loads the script using load, and returns void, which is translated into a 0 exit status for the script process.

```
(lambda (fn . fns)
 (command-line (cons fn fns))
 (command-line-arguments fns)
 (load fn))
```

scheme-script may be altered to start up an application or to perform customization prior to normal system start-up.

To have any effect, this parameter must be set within a boot file. (See Chapter 2)

The value of scheme-program is a procedure that determines the system’s action upon start-up when the --program (RNRS top-level program) option is used. The procedure receives one or more arguments. The first is a string identifying the program filename and the
remainder are strings representing the remaining file names (or command-line arguments not recognized by the Scheme executable) given on the command line. The default value of this parameter is a procedure that sets the command-line and command-line-arguments parameters, loads the program using load-program, and returns void, which is translated into a 0 exit status for the script process.

```scheme
(lambda (fn . fns)
  (command-line (cons fn fns))
  (command-line-arguments fns)
  (load-program fn))
```

**scheme-program** may be altered to start up an application or to perform customization prior to normal system start-up.

To have any effect, this parameter must be set within a boot file. (See Chapter 2.)

**command-line**

libraries: (chezscheme)

This parameter is set by the default values of **scheme-script** and **scheme-program** to a list representing the command line, with the script name followed by the command-line arguments, when the **--script** or **--program** option is used on system startup.

**command-line-arguments**

libraries: (chezscheme)

This parameter is set by the default values of **scheme-script** and **scheme-program** to a list of the command-line arguments when the **--script** or **--program** option is used on system startup.

**suppress-greeting**

libraries: (chezscheme)

The value of **suppress-greeting** is a boolean value that determines whether Chez Scheme prints an identifying banner and copyright notice. The parameter defaults to #f but may be set to #t for use in batch processing applications where the banner would be disruptive.

To have any effect, this parameter must be set within a boot file. (See Chapter 2)

### 12.9. Transcript Files

A transcript file is a record of an interactive session. It is also useful as a “quick-and-dirty” alternative to opening an output file and using explicit output operations.
(transcript-on path) \hspace{5mm} \text{procedure}

returns: unspecified
libraries: (chezscheme)

path must be a string.

transcript-on opens the file named by path for output, and it copies to this file all input from the current input port and all output to the current output port. An exception is raised with condition-type i/o-filename if the file cannot be opened for output.

(transcript-off) \hspace{5mm} \text{procedure}

returns: unspecified
libraries: (chezscheme)

transcript-off ends transcription and closes the transcript file.

(transcript-cafe path) \hspace{5mm} \text{procedure}

libraries: (chezscheme)

path must be a string. transcript-cafe opens a transcript file as with transcript-on and enters a new café; exiting from this café (see exit) also ends transcription and closes the transcript file. Invoking transcript-off while in a transcript café ends transcription and closes the transcript file but does not cause an exit from the café.

12.10. Times and Dates

This section documents procedures for handling times and dates. Most of the procedures described here are proposed in SRFI 19: Time Data Types and Procedures, by Will Fitzgerald.

Times are represented by time objects. Time objects record the nanosecond and second of a particular time or duration, along with a time type that identifies the nature of the time object. The time type is one of the following symbols:

\textbf{time-utc}: The time elapsed since the “epoch:” 00:00:00 UTC, January 1, 1970, subject to adjustment, e.g., to correct for leap seconds.

\textbf{time-monotonic}: The time elapsed since some arbitrary point in the past, ideally not subject to adjustment.

\textbf{time-duration}: The time elapsed between two times. When used as an argument to current-time, it behaves like time-monotonic, but may also used to represent the result of subtracting two time objects.

\textbf{time-process}: The amount of CPU time used by the current process.

\textbf{time-thread}: The amount of CPU time used by the current thread. It is the same as time-process if not running threaded or if the system does not allow individual thread times to be determined.
time-collector-cpu: The portion of the current process’s CPU time consumed by the garbage collector.

time-collector-real: The portion of the current process’s real time consumed by the garbage collector.

A time-object second is an exact integer (possibly negative), and a nanosecond is an exact nonnegative integer less than $10^9$. The second and nanosecond of a time object may be converted to an aggregate nanosecond value by scaling the seconds by $10^9$ and adding the nanoseconds. Thus, if the second and nanosecond of a time object are 5 and 10, the time object represents 5000000010 nanoseconds (5.000000010 seconds). If the second and nanosecond are -5 and 10, the time object represents -4999999990 nanoseconds (-4.999999990 seconds).

Dates are represented by date objects. A date object records the nanosecond, second, minute, hour, day, month, and year of a particular date, along with an offset that identifies the time zone.

As for time objects, a nanosecond is an exact integer less than $10^9$. A date-object second is, however, an exact nonnegative integer less than 62. (The values 61 and 62 allow for leap seconds.) A minute is an exact nonnegative integer less than 60, and an hour is an exact nonnegative integer less than 24. A day is an exact nonnegative integer in ranging from 1 representing the first day of the month to $n$, where $n$ is the number of days in the date’s month and year. A month is an exact nonnegative integer ranging from 1 through 12, where 1 represents January, 2 represents February, and so on. A year must be an exact integer. Years less than 1970 or greater than 2038 may not be supported depending on limitations of the underlying implementation. A time-zone offset represents the time-zone offset, in seconds, from UTC. It is an exact integer in the range $-86400$ to $+86400$, inclusive. For example, Eastern Standard Time (EST), which is 5 hours east, has offset $5 \times 3600 = -18000$. The offset for Eastern Daylight Time (EDT) is $-14400$. UTC is represented by offset zero.

```
(procedure (current-time))

(procedure (current-time time-type))

returns: a time object representing the current time

libraries: (chezscheme)

(time-type) must be one of the time-type symbols listed above and defaults to time-utc.

(current-time) ⇒ #<time-utc 1198815722.473668000>

(current-time 'time-process) ⇒ #<time-process 0.120534264>
```

```
(procedure (make-time type nsec sec))

returns: a time object

libraries: (chezscheme)

(type) must be one of the time-type symbols listed above. nsec represents nanoseconds and must be an exact nonnegative integer less than $10^9$. sec represents seconds and must be
```
an exact integer.

```
(make-time 'time-utc 787511000 1198783214)
(make-time 'time-duration 10 5)
(make-time 'time-duration 10 -5)
```

```
(time?  obj)  procedure
returns: #t if  obj  is a time object, #f otherwise
libraries: (chezscheme)
```

```
(time? (current-time))  ⇒  #t
(time? (make-time 'time-utc 0 0))  ⇒  #t
(time? "1400 hours")  ⇒  #f
```

```
(time-type  time)  procedure
returns: the time type of  time
(time-nanosecond  time)  procedure
returns: the nanosecond of  time
(time-second  time)  procedure
returns: the second of  time
libraries: (chezscheme)
```

*time* must be a time object.

```
(time-type (current-time))  ⇒  time-utc
(time-type (current-time 'time-process))  ⇒  time-process
(time-type (make-time 'time-duration 0 50))  ⇒  time-duration
(time-second (current-time))  ⇒  1198816497
(time-nanosecond (current-time))  ⇒  2399000
(time-second (make-time 'time-duration 10 -5))  ⇒  -5
(time-nanosecond (make-time 'time-duration 10 -5))  ⇒  10
```

```
(set-time-type!  time  type)  procedure
returns: unspecified
(set-time-nanosecond!  time  nsec)  procedure
returns: unspecified
(set-time-second!  time  sec)  procedure
returns: unspecified
libraries: (chezscheme)
```

*time* must be a time object.  *type* must be one of the time-type symbols listed above.

*nsec* represents nanoseconds and must be an exact nonnegative integer less than $10^9$.  *sec* represents seconds and must be an exact integer.

Each of these procedures modifies the time object, changing one aspect while leaving the others unaffected. For example, *set-time-nanosecond!* changes the nanosecond of *time*
without changing the second or type. In particular, no conversion of values is performed when the type of a time object is changed.

| (time=? time₁ time₂) | procedure |
| (time<? time₁ time₂) | procedure |
| (time<=? time₁ time₂) | procedure |
| (time=>? time₁ time₂) | procedure |
| (time>? time₁ time₂) | procedure |

returns: #t if the relation holds, #f otherwise

libraries: (chezscheme)

time₁ and time₂ must be time objects and must have the same type.

```scheme
(let ([t (current-time)])
  (time=? t t) ⇒ #t
(let ([t (current-time)])
  (let loop ()
    (when (time=? (current-time) t))
      (loop))
  (time>? (current-time) t)) ⇒ #t

(copy-time time) procedure
returns: a copy of time
libraries: (chezscheme)

(define t1 (current-time))
(define t2 (copy-time t1))
(eq? t2 t1) ⇒ #f
(eqv? (time-second t2) (time-second t1)) ⇒ #t
(eqv? (time-nanosecond t2) (time-nanosecond t1)) ⇒ #t

(time-difference time₁ time₂) procedure
returns: the result of subtracting time₂ from time₁
(time-difference! time₁ time₂) procedure
returns: the result of subtracting time₂ from time₁
(add-duration time time₅) procedure
returns: the result of adding time₅ to time
(add-duration! time time₅) procedure
returns: the result of adding time₅ to time
(subtract-duration time time₅) procedure
returns: the result of subtracting time₅ from time
(subtract-duration! time time₅) procedure
returns: the result of subtracting time₅ from time
libraries: (chezscheme)

For time-difference, time₁ and time₂ must have the same time type, and the result
is a time object with time type time-duration. For add-duration, add-duration!, subtract-duration, and subtract-duration!, timed must have time type time-duration, and the result is a time object with the same time type as time. time-difference!, add-duration!, and subtract-duration! are potentially destructive, i.e., each might modify and return its first argument, or it might allocate a new time object.

(let ([delay (make-time 'time-duration 0 1)])
  (let ([t1 (current-time 'time-monotonic)])
    (sleep delay)
    (let ([t2 (current-time 'time-monotonic)])
      (let ([t3 (time-difference t2 t1)])
        (and
         (eq? (time-type t3) 'time-duration)
         (time>=? t3 delay)
         (time=? (add-duration t1 t3) t2)
         (time=? (subtract-duration t2 t3 t1))))) → #t

(current-date) procedure
(current-date offset) procedure
returns: a date object representing the current date
libraries: (chezscheme)

offset represents the time-zone offset in seconds east of UTC, as described above. It must be an exact integer in the range −86400 to +86400, inclusive and defaults to the local time-zone offset. UTC may be obtained by passing an offset of zero.

If offset is not provided, then the current time zone’s offset is used, and date-dst? and date-zone-name report information about the time zone. If offset is provided, then date-dst? and date-zone-name on the resulting date object produce #f.

The following examples assume the local time zone is EST.

(current-date) ⇒ #<date Thu Dec 27 23:23:20 2007>
(current-date 0) ⇒ #<date Fri Dec 28 04:23:20 2007>

(date-zone-name (current-date)) ⇒ "EST" or other system-provided string
(date-zone-name (current-date 0)) ⇒ #f

(make-date nsec sec min hour day mon year) procedure
(make-date nsec sec min hour day mon year offset) procedure
returns: a date object
libraries: (chezscheme)

nsec represents nanoseconds and must be an exact nonnegative integer less than 10⁹. sec represents seconds and must be an exact nonnegative integer less than 62. min represents minutes and must be an exact nonnegative integer less than 60. hour must be an exact nonnegative integer less than 24. day must be an exact integer, 1 ≤ day ≤ 31. (The actual upper limit may be less depending on the month and year.) mon represents the month must be an exact integer, 1 ≤ mon ≤ 12. year must be an exact integer. It should be
at least 1970. \( \text{offset} \) represents the time-zone offset in seconds east of UTC, as described above. It must be an exact integer in the range \(-86400\) to \(+86400\), inclusive. UTC may be specified by passing an offset of zero.

If \( \text{offset} \) is not provided, then the current time zone’s offset is used, and \text{date-dst?} and \text{date-zone-name} report information about the time zone. If \( \text{offset} \) is provided, then \text{date-dst?} and \text{date-zone-name} on the resulting date object produce \#f.

\[
\begin{align*}
&\text{(make-date 0 0 0 1 1 1970 0) } \Rightarrow \text{ #<date Thu Jan 1 00:00:00 1970>} \\
&\text{(make-date 0 30 7 9 23 9 2007 -14400) } \Rightarrow \text{ #<date Sun Sep 23 09:07:30 2007>}
\end{align*}
\]

\[
\begin{align*}
&(\text{date-zone-name (make-date 0 30 7 9 23 9 2007 -14400)}) \Rightarrow \text{ #f} \\
&(\text{string? (date-zone-name (make-date 0 30 7 9 23 9 2007))}) \Rightarrow \text{ #t}
\end{align*}
\]

\[
\begin{align*}
&(\text{date-nanosecond date}) \quad \text{procedure} \\
&\text{returns: the nanosecond of } \text{date} \\
&(\text{date-second date}) \quad \text{procedure} \\
&\text{returns: the second of } \text{date} \\
&(\text{date-minute date}) \quad \text{procedure} \\
&\text{returns: the minute of } \text{date} \\
&(\text{date-hour date}) \quad \text{procedure} \\
&\text{returns: the hour of } \text{date} \\
&(\text{date-day date}) \quad \text{procedure} \\
&\text{returns: the day of } \text{date} \\
&(\text{date-month date}) \quad \text{procedure} \\
&\text{returns: the month of } \text{date} \\
&(\text{date-year date}) \quad \text{procedure} \\
&\text{returns: the year of } \text{date} \\
&(\text{date-zone-offset date}) \quad \text{procedure} \\
&\text{returns: the time-zone offset of } \text{date} \\
\end{align*}
\]

\[
\begin{align*}
&(\text{define d (make-date 0 30 7 9 23 9 2007 14400)}) \\
&(\text{date-nanosecond d}) \Rightarrow \text{ 0} \\
&(\text{date-second d}) \Rightarrow \text{ 30} \\
&(\text{date-minute d}) \Rightarrow \text{ 7} \\
&(\text{date-hour d}) \Rightarrow \text{ 9} \\
&(\text{date-day d}) \Rightarrow \text{ 23}
\end{align*}
\]
12.10. Times and Dates

\[(\text{date-month } d) \Rightarrow 9\]
\[(\text{date-year } d) \Rightarrow 2007\]
\[(\text{date-zone-offset } d) \Rightarrow -14400\]

\[(\text{date-week-day } date)\]
\text{procedure}
\text{returns: the week-day of } date

\[(\text{date-year-day } date)\]
\text{procedure}
\text{returns: the year-day of } date

\text{libraries: (chezscheme)}

These procedures allow the day-of-week or day-of-year to be determined for the date represented by \( date \). A week-day is an exact nonnegative integer less than 7, where 0 represents Sunday, 1 represents Monday, and so on. A year-day is an exact nonnegative integer less than 367, where 0 represents the first day of the year (January 1), 1 the second day, 2 the third, and so on.

\[(\text{define } d1 \ (\text{make-date} 0 \ 0 \ 0 \ 1 \ 1 \ 1970 \ -18000))\]
\[d1 \Rightarrow \#<\text{date Thu Jan 1 00:00:00 1970}>\]
\[(\text{date-week-day } d1) \Rightarrow 4\]
\[(\text{date-year-day } d1) \Rightarrow 0\]

\[(\text{define } d2 \ (\text{make-date} 0 \ 30 \ 7 \ 9 \ 23 \ 9 \ 2007 \ -14400))\]
\[d2 \Rightarrow \#<\text{date Sun Sep 23 09:07:30 2007}>\]
\[(\text{date-week-day } d2) \Rightarrow 0\]
\[(\text{date-year-day } d2) \Rightarrow 265\]

\[(\text{date-dst? } date)\]
\text{procedure}
\text{returns: whether } date \text{ is in Daylight Saving Time}

\[(\text{date-zone-name } date)\]
\text{procedure}
\text{returns: \#f or a string naming the time zone of } date

\text{libraries: (chezscheme)}

These procedures report time-zone information for the date represented by \( date \) for a date object that is constructed without an explicit time-zone offset. When a date object is created instead with explicit time-zone offset, these procedures produce \#f.

Daylight Saving Time status for the current time zone and a name string for the time zone are computed using platform-specific routines. In particular, the format of the zone name is platform-specific.

\[(\text{define } d \ (\text{make-date} 0 \ 30 \ 7 \ 9 \ 23 \ 9 \ 2007))\]
\[(\text{date-zone-offset } d) \Rightarrow -14400 \text{ assuming Eastern U.S. time zone}\]
\[(\text{date-dst? } d) \Rightarrow \#t\]
\[(\text{date-zone-name } d) \Rightarrow "EDT" \text{ or some system-provided string}\]
(time-utc->date time)
(procedure)
returns: a date object corresponding to time

(time-utc->date time offset)
(procedure)
returns: a date object corresponding to time

(date->time-utc date)
(procedure)
returns: a time object corresponding to date

libraries: (chezscheme)

These procedures are used to convert between time and date objects. The \textit{time} argument to \textit{time-utc->date} must have time-type \textit{utc}, and \textit{date->time-utc} always returns a time object with time-type \textit{utc}.

For \textit{time-utc->date}, \textit{offset} represents the time-zone offset in seconds east of UTC, as described at the beginning of this section. It must be an exact integer in the range \(-86400\) to +86400, inclusive and defaults to the local time-zone offset. UTC may be obtained by passing an offset of zero.

If \textit{offset} is not provided to \textit{time-utc->date}, then the current time zone’s offset is used, and \textit{date-dst?} and \textit{date-zone-name} report information about the time zone. If \textit{offset} is provided, then \textit{date-dst?} and \textit{date-zone-name} on the resulting date object produce \#f.

\begin{verbatim}
(define d (make-date 0 30 7 9 23 9 2007 -14400))
(date->time-utc d) ⇒ #<time-utc 1190552850.000000000>
(define t (make-time 'time-utc 0 1190552850))
(time-utc->date t) ⇒ #<date Sun Sep 23 09:07:30 2007>
(time-utc->date t 0) ⇒ #<date Sun Sep 23 13:07:30 2007>
\end{verbatim}

(date-and-time)
(procedure)
returns: a string giving the current date and time

libraries: (chezscheme)

The string is always in the format illustrated by the examples below and always has length 24.

\begin{verbatim}
(date-and-time) ⇒ "Fri Jul 13 13:13:13 2001"
(define d (make-date 0 0 0 0 1 1 2007 0))
(date-and-time d) ⇒ "Mon Jan 01 00:00:00 2007"
\end{verbatim}

(sleep time)
(procedure)
returns: unspecified

libraries: (chezscheme)

time must be a time object with type \textit{time-duration}. \textit{sleep} causes the invoking thread to suspend operation for approximately the amount of time indicated by the time object, unless the process receives a signal that interrupts the sleep operation. The actual time slept depends on the granularity of the system clock and how busy the system is running other threads and processes.
12.11. Timing and Statistics

This section documents procedures for timing computations. The current-time procedure described in Section 12.10 may also be used to time computations.

(time expr) syntax
returns: the values of expr
libraries: (chezscheme)

time evaluates expr and, as a side-effect, prints (to the console-output port) the amount of cpu time, the amount of real time, the number of bytes allocated, and the amount of collection overhead associated with evaluating expr.

> (time (collect))
(time (collect))
  1 collection
  1 ms elapsed cpu time, including 1 ms collecting
  1 ms elapsed real time, including 1 ms collecting
  160 bytes allocated, including 8184 bytes reclaimed

(display-statistics) procedure
(display-statistics textual-output-port) procedure
returns: unspecified
libraries: (chezscheme)

This procedure displays a running total of the amount of cpu time, real time, bytes allocated, and collection overhead. If textual-output-port is not supplied, it defaults to the current output port.

(cpu-time) procedure
returns: the amount of cpu time consumed since system start-up
libraries: (chezscheme)

The amount is in milliseconds. The amount includes “system” as well as “user” time, i.e., time spent in the kernel on behalf of the process as well as time spent in the process itself. See also current-time, which returns more precise information.

(real-time) procedure
returns: the amount of real time that has elapsed since system start-up
libraries: (chezscheme)

The amount is in milliseconds. See also current-time, which returns more precise information.
(bytes-allocated) procedure
returns: the number of bytes currently allocated
libraries: (chezscheme)

If \( g \) is supplied, \texttt{bytes-allocated} returns the number of bytes currently allocated for Scheme objects in the specified generation plus externally allocated bytes as represented by phantom bytevectors in the generation. \( g \) must be a nonnegative exact integer no greater than the maximum nonstatic generation, i.e., the value returned by \texttt{collect-maximum-generation}, or the symbol \texttt{static}. If \( g \) is not supplied, \texttt{bytes-allocated} returns the total number of bytes allocated in all generations.

(initial-bytes-allocated) procedure
returns: the total number of bytes allocated after loading boot files
libraries: (chezscheme)

(bytes-deallocated) procedure
returns: the total number of bytes deallocated by the garbage collector
libraries: (chezscheme)

The total number of bytes allocated by the current process, whether still in use or not, can be obtained by summing \texttt{bytes-deallocated} and \texttt{bytes-allocated} and possibly subtracting \texttt{initial-bytes-allocated}.

(bytes-finalized) procedure
returns: the number of bytes queued in guardians
libraries: (chezscheme)

The number of bytes associated with objects that were registered in guardians as otherwise inaccessible (including the bytes for objects reachable only through registered objects) during the most recent garbage collection.

(current-memory-bytes) procedure
returns: the total number of bytes currently allocated, including overhead
libraries: (chezscheme)

\texttt{current-memory-bytes} returns the total size of the heap in bytes, including not only the bytes occupied for Scheme objects but also various forms of overhead, including fragmentation and reserved but not currently occupied memory, and is thus an accurate measure of the amount of heap memory currently reserved from the operating system for the current process. The result is only for Scheme’s storage management, however, so it does not include sizes for externally allocated objects (even those that are represented by phantom bytevectors).
12.11. Timing and Statistics

(maximum-memory-bytes) procedure
returns: the maximum number of bytes ever allocated, including overhead
libraries: (chezscheme)

maximum-memory-bytes returns the maximum size of the heap in bytes, i.e., the maximum
value that current-memory-bytes returned or could have returned, since the last call to
reset-maximum-memory-bytes! or, if there has been no such call, since the process started.

(reset-maximum-memory-bytes!) procedure
returns: unspecified
libraries: (chezscheme)

reset-maximum-memory-bytes! resets the maximum recorded size of the heap to the current
size of the heap.

(collections) procedure
returns: the number garbage collections so far
libraries: (chezscheme)

(statistics) procedure
returns: a sstats record containing current statistics
libraries: (chezscheme)

statistics packages together various timing and allocation statistics into a single sstats
record. A sstats record has the following fields:

cpu, the cpu time consumed,
real, the elapsed real time,
bytes, the number of bytes allocated,
gc-count, the number of collections,
gc-cpu, the cpu time consumed during collections,
gc-real, the elapsed real time during collections, and
gc-bytes, the number of bytes reclaimed by the collector.

All values are computed since system start-up. The time values are time objects (Section 12.10), and the bytes and count values are exact integers.

statistics might be defined as follows:
12. System Operations

(define statistics
  (lambda ()
    (make-sstats
      (current-time 'time-thread)
      (current-time 'time-monotonic)
      (- (+ (bytes-allocated) (bytes-deallocated))
          (initial-bytes-allocated))
      (collections)
      (current-time 'time-collector-cpu)
      (current-time 'time-collector-real)
      (bytes-deallocated))))

(make-sstats cpu real bytes gc-count gc-cpu gc-real gc-bytes) procedure
returns: a sstats record
libraries: (chezscheme)

The time arguments (cpu, real, gc-cpu, and gc-real) must be time objects. The other arguments must be exact integers.

(sstats? obj) procedure
returns: #t if obj is a sstats record, otherwise #f
libraries: (chezscheme)

(sstats-cpu s) procedure
(sstats-real s) procedure
(sstats-bytes s) procedure
(sstats-gc-count s) procedure
(sstats-gc-cpu s) procedure
(sstats-gc-real s) procedure
(sstats-gc-bytes s) procedure
returns: the value of the corresponding field of s
libraries: (chezscheme)

s must be a sstats record.

(set-sstats-cpu! s new-value) procedure
(set-sstats-real! s new-value) procedure
(set-sstats-bytes! s new-value) procedure
(set-sstats-gc-count! s new-value) procedure
(set-sstats-gc-cpu! s new-value) procedure
(set-sstats-gc-real! s new-value) procedure
(set-sstats-gc-bytes! s new-value) procedure
returns: unspecified
libraries: (chezscheme)

s must be a sstats record, the new-value arguments for the time fields (cpu, real, gc-cpu,
and gc-real) must be time objects, and the other new-value arguments must be exact integers. Each procedure sets the value of the corresponding field of s to new-value.

\[(\text{sstats-difference } s_1 \ s_2)\] 
\text{procedure}

returns: a sstats record representing the difference between \(s_1\) and \(s_2\) 
libraries: (chezscheme)

\(s_1\) and \(s_2\) must be sstats records. sstats-difference subtracts each field of \(s_2\) from the corresponding field of \(s_1\) to produce the resulting sstats record.

\[(\text{sstats-print } s)\] 
\text{procedure}

\[(\text{sstats-print } s \ \text{textual-output-port})\] 
\text{procedure}

returns: unspecified 
libraries: (chezscheme)

\(s\) must be a sstats record. If \(\text{textual-output-port}\) is not supplied, it defaults to the current output port. sstats-print displays the fields of \(s\) in a manner similar to display-statistics and time.

enable-object-counts 
\text{global parameter}

libraries: (chezscheme)

The value of enable-object-counts is a boolean value that determines whether the collector records object counts as it runs and hence whether the object counts returned by the procedure object-counts are accurate. The parameter is set to #f by default, since enabling object counts adds overhead to collection.

Counts for the static generation are always correct. Counts for a nonstatic generation \(n\) are correct immediately after a collection of generation \(m \geq n\) (regardless of whether the target generation is \(m\) or \(m + 1\)) if enable-object-counts was set to #t during the collection.

One strategy for collecting object counts with minimal overhead is to enable object counts only while collecting the maximum nonstatic generation and to obtain the object counts immediately after that collection.

\[(\text{object-counts})\] 
\text{procedure}

returns: see below 
libraries: (chezscheme)

The procedure object-counts returns a nested association list representing object counts and bytes allocated for each heap-allocated primitive type and record type with at least one live instance in one or more generations. (Heap-allocated primitive types include, e.g., pairs and vectors, but not, e.g., fixnums or characters.) Object counts are gathered by the collector only when enable-object-counts is #t. The description of enable-object-counts details the circumstances under which the counts are accurate.

The association list returned by object-counts has the following structure:
((type (generation count . bytes) ...) ...)

type is either the name of a primitive type, represented as a symbol, e.g., pair, or a
record-type descriptor (rtd). generation is a nonnegative fixnum between 0 and the value
of (collect-maximum-generation), inclusive, or the symbol static representing the static
generation. count and bytes are nonnegative fixnums.

(collect-request-handler void)
(enable-object-counts #t)
(define-record-type frob (fields x))
(define x (make-frob (make-frob #f)))
(collect 3 3)
(cdr (assoc 3
  (cdr (assoc (record-type-descriptor frob)
    (object-counts)))))) ⇒ (2 . 16)

enable-object-backreferences

The value of enable-object-backreferences is a boolean value that determines whether
the collector records information about which other object caused an object to be retained
and hence whether the backreferences reported by the procedure object-backreferences
are accurate. The parameter is set to #f by default, since backreference recording adds
overhead to collection.

Beware that backreference recording can have small performance effects even after it is
disabled—at least until the next collection over the same generations—since backreference
records constrain the way that the collector stores some objects.

(object-backreferences)

The procedure object-backreferences returns a list of backreference lists. Each backref-
erence list is a list of pairs, where the car of the pair is a referenced object, and the cdr of
the pair is either #f or a value that caused the car’s value or be retained during collection.
The cdr of a backreference pair is #f if the object in the car is retained by a root reference
within the system’s implementation or static generation. By locating the cdr of one pair
as the car of another, chains of objects as discovered by the collector can be traced back
to roots.

The list returned by object-backreferences contains one backreference list for each non-
static generation (in order, starting with generation 0). An object is recorded in a backref-
erence list for the destination generation to which it is moved by collection. The collector
records backreference information only when enable-object-backreferences is set to a
true value, and only for objects that start in generations that are collected.

For example, assuming that backreferences have not been previously enabled, the result of
will have a non-empty backreference list only for the second list in the result (i.e., the list for generation 1).

Although `object-backreferences` reports generation-specific information to reflect its cooperation with generational collection, backreference information is most useful after a collection of all generations up to the maximum nonstatic generation. In that case, backreference information can be used to discover why a particular value or kind of value remains allocated or remains in a weak pair after garbage collection.

```scheme
(collect-request-handler void)
(enable-object-backreferences #t)
(collect 0)
(enable-object-backreferences #f)
(object-backreferences)
```

12.12. Cost Centers

Cost centers are used to track the bytes allocated, instructions executed, and/or cpu time elapsed while evaluating selected sections of code. Cost centers are created via the procedure `make-cost-center`, and costs are tracked via the procedure `with-cost-center`.

Allocation and instruction counts are tracked only for code instrumented for that purpose. This instrumentation is controlled by two parameters: `generate-allocation-counts` and `generate-instruction-counts`. Instrumentation is disabled by default. Built in procedures are not instrumented, nor is interpreted code or non-Scheme code. Elapsed time is tracked only when the optional `timed?` argument to `with-cost-center` is provided and is not false.

The `with-cost-center` procedure accurately tracks costs, subject to the caveats above, even when reentered with the same cost center, used simultaneously in multiple threads, and exited or reentered one or more times via continuation invocation.

```scheme
(generate-allocation-counts thread parameter)
libraries: (chezscheme)
```

When this parameter has a true value, the compiler inserts a short sequence of instructions at each allocation point in generated code to track the amount of allocation that occurs. This parameter is initially false.

```scheme
(generate-instruction-counts thread parameter)
libraries: (chezscheme)
```

When this parameter has a true value, the compiler inserts a short sequence of instructions
in each block of generated code to track the number of instructions executed by that block. This parameter is initially false.

```scheme
(make-cost-center) procedure
returns: a new cost center
libraries: (chezscheme)
```

The recorded costs of the new cost center are initialized to zero.

```scheme
(cost-center? obj) procedure
returns: #t if obj is a cost center, otherwise #f
libraries: (chezscheme)
```

```scheme
(with-cost-center cost-center thunk) procedure
(with-cost-center timed? cost-center thunk) procedure
returns: see below
libraries: (chezscheme)
```

*thunk* must be a procedure that accepts zero arguments. *with-cost-center* invokes *thunk* without arguments and returns its values. It also tracks, dynamically, the bytes allocated, instructions executed, and cpu time elapsed while evaluating the invocation of *thunk* and adds the tracked costs to the cost center’s running record of these costs.

As described above, allocation counts are tracked only for code compiled with the parameter *generate-allocation-counts* set to true, and instruction counts are tracked only for code compiled with *generate-instruction-counts* set to true. Cpu time is tracked only if *timed?* is provided and not false and includes cpu time spent in instrumented, uninstrumented, and non-Scheme code.

```scheme
(cost-center-instruction-count cost-center) procedure
returns: the number of instructions tracked by *cost-center*
libraries: (chezscheme)
```

```scheme
(cost-center-allocation-count cost-center) procedure
returns: the number of allocated bytes tracked by *cost-center*
libraries: (chezscheme)
```

```scheme
(cost-center-time cost-center) procedure
returns: the cpu time tracked by *cost-center*
libraries: (chezscheme)
```

The cpu time is returned as a time object with time-type *time-duration*. 
This procedure resets the costs recorded by \textit{cost-center} to zero.

\subsection*{12.13. Parameters}

This section describes mechanisms for creating and manipulating parameters. New parameters may be created conveniently with \texttt{make-parameter}. Nothing distinguishes parameters from other procedures, however, except for their behavior. If more complicated actions must be taken when a parameter is invoked than can be accommodated easily through the \texttt{make-parameter} mechanism, the parameter may be defined directly with \texttt{case-lambda}.

\begin{verbatim}
(make-parameter object)

(make-parameter object procedure)

returns: a parameter (procedure)

libraries: (chezscheme)

\end{verbatim}

\texttt{make-parameter} accepts one or two arguments. The first argument is the initial value of the internal variable, and the second, if present, is a \texttt{filter} applied to the initial value and all subsequent values. The filter should accept one argument. If the value is not appropriate, the filter should raise an exception or convert the value into a more appropriate form.

For example, the default value of \texttt{print-length} is defined as follows:

\begin{verbatim}
(define print-length
  (make-parameter
    #f
    (lambda (x)
      (unless (or (not x) (and (fixnum? x) (fx>= x 0)))
        (assertion-violationf 'print-length
          "-s is not a positive fixnum or #f" x))
      x)))

(print-length) ⇒ #f
(print-length 3) ⇒ 3
(format "-s" '(1 2 3 4 5 6)) ⇒ "(1 2 3 ...)
(print-length #f)
(format "-s" '(1 2 3 4 5 6)) ⇒ "(1 2 3 4 5 6)"

\end{verbatim}

The definition of \texttt{make-parameter} is straightforward using \texttt{case-lambda}:
In threaded versions of Chez Scheme, \texttt{make-parameter} creates global parameters. The procedure \texttt{make-thread-parameter}, described in Section \[15.8\] may be used to make thread parameters.

\begin{verbatim}
(define make-parameter
  (case-lambda
    [(init guard)
      (let ([v (guard init)])
        (case-lambda
          [(u) (set! v (guard u))]
          [(init)
            (make-parameter init (lambda (x) x))])))

In threaded versions of Chez Scheme, \texttt{make-parameter} creates global parameters. The procedure \texttt{make-thread-parameter}, described in Section \[15.8\] may be used to make thread parameters.

\begin{verbatim}
\begin{Verbatim}
(\texttt{parameterize} ((\texttt{param} expr) ...) body\_1 body\_2 ...)
\end{Verbatim}
\end{verbatim}

\textbf{syntax returns:} the values of the body \texttt{body\_1} \texttt{body\_2} ...

\textbf{libraries:} (chezscheme)

Using the syntactic form \texttt{parameterize}, the values of parameters can be changed in a manner analogous to \texttt{fluid-let} for ordinary variables. Each \texttt{param} is set to the value of the corresponding \texttt{expr} while the body is evaluated. When control leaves the body by normal return or by the invocation of a continuation created outside of the body, the parameters are restored to their original values. If control returns to the body via a continuation created during the execution of the body, the parameters are again set to their temporary values.

\begin{verbatim}
(define test
  (make-parameter 0))
(test) ⇒ 0
(test 1)
(test) ⇒ 1
(parameterize ([test 2])
  (test)) ⇒ 2
(test) ⇒ 1
(parameterize ([test 2])
  (test 3)
  (test)) ⇒ 3
(test) ⇒ 1
(define k (lambda (x) x))
(begin (set! k (call/cc k))
  'k) ⇒ k
(parameterize ([test 2])
  (test (call/cc k))
  (test)) ⇒ k
(test) ⇒ 1
(k 3) ⇒ 3
(test) ⇒ 1
\end{verbatim}

The definition of \texttt{parameterize} is similar to the definition of \texttt{fluid-let} (page \[121\]:

\begin{verbatim}
\end{verbatim}
A limited set of virtual registers is supported by the compiler for use by programs that require high-speed, global, and mutable storage locations. Referencing or assigning a virtual register is potentially faster and never slower than accessing an assignable local or global variable, and the code sequences for doing so are generally smaller. Assignment is potentially significantly faster because there is no need to track pointers from the virtual registers to young objects, as there is for variable locations that might reside in older generations. On threaded versions of the system, virtual registers are “per thread” and thus serve as thread-local storage in a manner that is less expensive than thread parameters.

The interface consists of three procedures: \texttt{virtual-register-count}, which returns the number of virtual registers, \texttt{set-virtual-register!}, which sets the value of a specified virtual register, and \texttt{virtual-register}, which retrieves the value of a specified virtual register.

A virtual register is specified by a nonnegative fixnum index less than the number of virtual registers. To get optimal performance for \texttt{set-virtual-register!} and \texttt{virtual-register}, the index should be a constant embedded right in the call (or propagatable via optimization to the call). To avoid putting these constants in the source code, programmers should consider using identifier macros to give names to virtual registers, e.g.:

\begin{verbatim}
(define-syntax current-state
  (identifier-syntax
    [(id (virtual-register 0)]
    [(set! id e) (set-virtual-register! 0 e)])
  (set! current-state 'start)
  current-state ⇒ start
\end{verbatim}

A more elaborate macro could dole out indices at compile time and complain when no more indices are available.

Virtual-registers must be treated as an application-level resource, i.e., libraries intended to be used by multiple applications should generally not use virtual registers to avoid conflicts with an application’s use of the registers.
12. System Operations

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(virtual-register-count)</code></td>
<td>procedure</td>
<td>(chezscheme)</td>
</tr>
<tr>
<td></td>
<td>returns: the number of virtual registers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>As of Version 9.0, the number of virtual registers is set at 16. It cannot be changed except by recompiling Chez Scheme from source.</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(set-virtual-register! k x)</code></td>
<td>procedure</td>
<td>(chezscheme)</td>
</tr>
<tr>
<td></td>
<td>returns: unspecified</td>
<td></td>
</tr>
<tr>
<td><em>set-virtual-register! stores x in virtual register k. k must be a nonnegative fixnum less than the value of (virtual-register-count).</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(virtual-register k)</code></td>
<td>procedure</td>
<td>(chezscheme)</td>
</tr>
<tr>
<td></td>
<td>returns: see below</td>
<td></td>
</tr>
<tr>
<td><em>virtual-register returns the value most recently stored in virtual register k (on the current thread, in threaded versions of the system).</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12.15. Environmental Queries and Settings

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Returns</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(scheme-version)</code></td>
<td>procedure</td>
<td>(chezscheme)</td>
</tr>
<tr>
<td><code>(scheme-version show-pre-release?)</code></td>
<td>procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>returns: a version string</td>
<td></td>
</tr>
<tr>
<td>The version string is in the form</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

"Chez Scheme Version version"

for Chez Scheme, and

"Petite Chez Scheme Version version"

for Petite Chez Scheme.

*version* includes the major, minor, and patch version numbers separated by .. If *show-pre-release?* is provided and is a true value, and the current version is a pre-release version (i.e., *(scheme-pre-release)* is a number), then *version* additionally has `-pre-release`, and the pre-release number appended.

|(scheme-version) ⇒ "Chez Scheme Version 9.9.9"| *(scheme-version #t) ⇒ "Chez Scheme Version 9.9.9-pre-release.11"|
12.15. Environmental Queries and Settings

**(scheme-version-number)**  
returns: three values: the major, minor, and patch version numbers  
libraries: (chezscheme)

Each of the three return values is a nonnegative fixnum.

In *Chez Scheme* Version 9.7.3 or 9.7.3-pre-release.3:

```scheme
(scheme-version-number) ⇒ 9
                                    7
                                    3
```

**(scheme-pre-release)**  
returns: a pre-release number or #f  
libraries: (chezscheme)

The return value is a positive fixnum for a pre-release version, or it is #f for a release version (which is after any version that has a pre-release number and the same major, minor, and patch number).

In *Chez Scheme* Version 9.7.3:

```scheme
(scheme-pre-release) ⇒ #f
```

In *Chez Scheme* Version 9.7.3-pre-release.3:

```scheme
(scheme-pre-release) ⇒ 3
```

**(petite?)**  
returns: #t if called in *Petite Chez Scheme*, #f otherwise  
libraries: (chezscheme)

The only difference between *Petite Chez Scheme* and *Chez Scheme* is that the compiler is not available in the former, so this predicate can serve as a way to determine if the compiler is available.

**(threaded?)**  
returns: #t if called in a threaded version of the system, #f otherwise  
libraries: (chezscheme)

**(interactive?)**  
returns: #t if system is run interactively, #f otherwise  
libraries: (chezscheme)

This predicate returns #t if the Scheme process’s stdin and stdout are connected to a tty (Unix-based systems) or console (Windows). Otherwise, it returns #f.
12. System Operations

(get-process-id) procedure
returns: the operating system process id of the current process
libraries: (chezscheme)

(getenv key) procedure
returns: environment value of key or #f
libraries: (chezscheme)

key must be a string. getenv returns the operating system shell’s environment value associated with key, or #f if no environment value is associated with key.

(getenv "HOME") ⇒ "/u/freddy"

(putenv key value) procedure
returns: unspecified
libraries: (chezscheme)

key and value must be strings.

putenv stores the key, value pair in the environment of the process, where it is available to the current process (e.g., via getenv) and any spawned processes.

(putenv "SCHEME" "rocks!")
(putenv "SCHEME") ⇒ "rocks!"

(get-registry key) procedure
returns: registry value of key or #f
(put-registry! key val) procedure
(put-registry! key) procedure
returns: unspecified
libraries: (chezscheme)

key and val must be strings.

get-registry returns a string containing the registry value of key if the value exists. If no registry value for key exists, get-registry returns #f.

put-registry! sets the registry value of key to val. It raises an exception with condition type &assertion if the value cannot be set, which may happen if the user has insufficient access.

remove-registry! removes the registry key or value named by key. It raises an exception with condition type &assertion if the value cannot be removed. Reasons for failure include the key not being present, the user having insufficient access, or key being a key with subkeys.

These routines are defined for Windows only.
subset-mode thread parameter
libraries: (chezscheme)

The value of this parameter must be #f (the default) or the symbol system. Setting subset-mode to system allows the manipulation of various undocumented system variables, data structures, and settings. It is typically used only for system debugging.
This chapter describes aspects of the storage management system and procedures that may be used to control its operation.

13.1. Garbage Collection

Scheme objects such as pairs, strings, procedures, and user-defined records are never explicitly deallocated by a Scheme program. Instead, the storage management system automatically reclaims the storage associated with an object once it proves the object is no longer accessible. In order to reclaim this storage, Chez Scheme employs a garbage collector which runs periodically as a program runs. Starting from a set of known roots, e.g., the machine registers, the garbage collector locates all accessible objects, copies them (in most cases) in order to eliminate fragmentation between accessible objects, and reclaims storage occupied by inaccessible objects.

Collections are triggered automatically by the default collect-request handler, which is invoked via a collect-request interrupt that occurs after approximately $n$ bytes of storage have been allocated, where $n$ is the value of the parameter `collect-trip-bytes`. The default collect-request handler causes a collection by calling the procedure `collect` without arguments. The collect-request handler can be redefined by changing the value of the parameter `collect-request-handler`. A program can also cause a collection to occur between collect-request interrupts by calling `collect` directly either without or with arguments.

Chez Scheme’s collector is a generation-based collector. It segregates objects based on their age (roughly speaking, the number of collections survived) and collects older objects less frequently than younger objects. Since younger objects tend to become inaccessible more quickly than older objects, the result is that most collections take little time. The system also maintains a static generation from which storage is never reclaimed. Objects are placed into the static generation only when a heap is compacted (see `Scompact_heap` in Section [4.9]) or when an explicitly specified target-generation is the symbol `static`. This is primarily useful after an application’s permanent code and data structures have been loaded and initialized, to reduce the overhead of subsequent collections.

Nonstatic generations are numbered starting at zero for the youngest generation up through the current value of `collect-maximum-generation`. The storage manager places newly allocated objects into generation 0.

When `collect` is invoked without arguments, generation 0 objects that survive collection
move to generation 1, generation 1 objects that survive move to generation 2, and so on, except that objects are never moved past the maximum nonstatic generation. Objects in the maximum nonstatic generation are collected back into the maximum nonstatic generation. While generation 0 is collected during each collection, older generations are collected less frequently. An internal counter, gc-trip, is maintained to control when each generation is collected. Each time `collect` is called without arguments (as from the default collect-request handler), gc-trip is incremented by one, and the set of generations to be collected is determined from the current value of gc-trip and the value of `collect-generation-radix`: with a collect-generation radix of \( r \), the maximum collected generation is the highest numbered generation \( g \) for which gc-trip is a multiple of \( r^g \). If `collect-generation-radix` is set to 4, the system thus collects generation 0 every time, generation 1 every 4 times, generation 2 every 16 times, and so on.

The maximum generation \( mg \) is collected on the gc-trip schedule only if the total amount of allocated memory before collection is \( k \) times the total amount of allocated memory after the previous collection of \( mg \), where the \( k \) is the value of `collect-maximum-generation-threshold-factor`. If a collection of \( mg \) is skipped by this rule, then gc-trip is rewound to the previous value that is a multiple of \( r^{mg-1} \) (so that the next time to collect \( mg - 1 \) is potentially also a time to collect \( mg \)). The intent of this \( k \) factor is to avoid unnecessary traversal of long-lived objects when rapidly allocating short-lived objects; for objects that will live until the end of a process, promoting them to the static generation can be even more effective, but promotion requires additional reasoning to ensure that an object is not retained inappropriately, while the `collect-maximum-generation-threshold-factor` parameter allows the collector to adapt more automatically.

When `collect` is invoked with arguments, the generations to be collected and their target generations are determined by the arguments. In addition, the first argument \( cg \) affects the value of gc-trip; that is, gc-trip is advanced to the next \( r^{cg} \) boundary, but not past the next \( r^{cg+1} \) boundary, where \( r \) is the value of `collect-generation-radix`.

It is possible to make substantial adjustments in the collector’s behavior by setting the parameters described in this section. It is even possible to completely override the collector’s default strategy for determining when each generation is collected by redefining the collect-request handler to call `collect` with arguments. For example, the programmer can redefine the handler to treat the maximum nonstatic generation as a static generation over a long period of time by calling `collect` with arguments that prevent the maximum nonstatic generation from being collected during that period of time.

Additional information on Chez Scheme’s collector can be found in the report “Don’t stop the BiBOP: Flexible and efficient storage management for dynamically typed languages” [13].
13.1. Garbage Collection

This procedure causes the storage manager to perform a garbage collection. `collect` is invoked periodically without arguments by the default collect-request handler, but it may also be called explicitly, e.g., from a custom collect-request handler, between phases of a computation when collection is most likely to be successful, or before timing a computation. In the threaded versions of Chez Scheme, the thread that invokes `collect` must be the only active thread.

When called without arguments, the system determines automatically which generations to collect and the target generation for each collected generation as described in the lead-in to this section.

When called with arguments, the system collects all and only objects in generations less than or equal to `cg` (the maximum collected generation) into the target generation or generations determined by `min-tg` (the minimum target generation) and `max-tg` (the maximum target generation). Specifically, the target generation for any object in a collected generation `g` is `min(max(g + 1, min-tg), max-tg)`, where `static` is taken to have the value one greater than the maximum nonstatic generation.

If present, `cg` must be a nonnegative fixnum no greater than the maximum nonstatic generation, i.e., the current value of the parameter `collect-maximum-generation`.

If present, `max-tg` must be a nonnegative fixnum or the symbol `static` and either equal to `cg` or one greater than `cg`, again treating `static` as having the value one greater than the maximum nonstatic generation. If `max-tg` is not present (but `cg` is), it defaults to `cg` if `cg` is equal to the maximum target generation and to one more than `cg` otherwise.

If present, `min-tg` must be a nonnegative fixnum or the symbol `static` and no greater than `max-tg`, again treating `static` as having the value one greater than the maximum nonstatic generation. Unless `max-cg` is the same as `cg`, `min-tg` must also be greater than `cg`. If `min-tg` is not present (but `cg` is), it defaults to the same value as `max-tg`.

If present, `objs` must be either `#f` or a list. If `objs` is a list, the collection is combined with counting as in `compute-size-increments`. Counting looks through all generations, as when `'static` is the second argument to `compute-size-increments`, but the returned sizes from `collect` do not include any objects in a generation older than `g`. Another difference is that an object later in `objs` is treated as unreachable by earlier objects in `objs` only when the later object is a record, thread, or procedure (including continuations). Finally, if an object is included in `objs` using a weak pair, then the object’s result size is 0 unless it is reachable from earlier objects; if the object is not reachable at all, it can be collected.
(collect-rendezvous)  
procedure returns: unspecified  
libraries: (chezscheme)

Requests a garbage collection in the same way as when the system determines that a collection should occur. All running threads are coordinated so that one of them calls the collect-request handler, while the other threads pause until the handler returns. If the initial thread is active at the time of the rendezvous, it is used to call the collect-request handler.

Note that if the collect-request handler (see collect-request-handler) does not call collect, then collect-rendezvous does not actually perform a garbage collection.

collect-notify  
global parameter  
libraries: (chezscheme)

If collect-notify is set to a true value, the collector prints a message whenever a collection is run. collect-notify is set to #f by default.

collect-trip-bytes  
global parameter  
libraries: (chezscheme)

This parameter determines the approximate amount of storage that is allowed to be allocated between garbage collections. Its value must be a positive fixnum.

Chez Scheme allocates memory internally in large chunks and subdivides these chunks via inline operations for efficiency. The storage manager determines whether to request a collection only once per large chunk allocated. Furthermore, some time may elapse between when a collection is requested by the storage manager and when the collect request is honored, especially if interrupts are temporarily disabled via with-interrupts-disabled or disable-interrupts. Thus, collect-trip-bytes is an approximate measure only.

collect-generation-radix  
global parameter  
libraries: (chezscheme)

This parameter determines how often each generation is collected when collect is invoked without arguments, as by the default collect-request handler. Its value must be a positive fixnum. Generations are collected once every $r^g$ times a collection occurs, where $r$ is the value of collect-generation-radix and $g$ is the generation number.

Setting collect-generation-radix to one forces all generations to be collected each time a collection occurs. Setting collect-generation-radix to a very large number effectively delays collection of older generations indefinitely.

collect-maximum-generation-threshold-factor  
global parameter  
libraries: (chezscheme)

This parameter determines how often the maximum generation is collected when collect
is invoked without arguments, as by the default collect-request handler. Its value must be a nonnegative real number. The maximum generation is collected only when the total amount of allocated memory before a collection is \( k \) times the amount of memory allocated after the most recent collection of the maximum generation, where \( k \) is the value of `collect-maximum-generation-threshold-factor`.

Setting `collect-maximum-generation-threshold-factor` to zero causes every regularly scheduled collection of the maximum generation to take place. Setting the value of `collect-maximum-generation-threshold-factor` to a large number can increase peak memory use by delaying collection of the maximum generation.

---

`collect-maximum-generation` **global parameter**

libraries: (chezscheme)

This parameter determines the maximum nonstatic generation, hence the total number of generations, currently in use. Its value is an exact integer in the range 1 through 6. When set to 1, only two nonstatic generations are used; when set to 2, three nonstatic generations are used, and so on. When set to 6, 7 nonstatic generations are used, plus the single static generation for a total of 8 generations. Increasing the number of generations effectively decreases how often old objects are collected, potentially decreasing collection overhead but potentially increasing the number of inaccessible objects retained in the system and thus the total amount of memory required.

---

`collect-request-handler` **global parameter**

libraries: (chezscheme)

The value of `collect-request-handler` must be a procedure. The procedure is invoked without arguments whenever the system determines that a collection should occur, i.e., some time after an amount of storage determined by the parameter `collect-trip-bytes` has been allocated since the last collection.

By default, `collect-request-handler` simply invokes `collect` without arguments.

Automatic collection may be disabled by setting `collect-request-handler` to a procedure that does nothing, e.g.:

```
(collect-request-handler void)
```

Collection can also be temporarily disabled using `critical-section`, which prevents any interrupts from being handled.

In the threaded versions of Chez Scheme, the collect-request handler is invoked by a single thread with all other threads temporarily suspended.

---

`release-minimum-generation` **global parameter**

libraries: (chezscheme)

This parameter’s value must be between 0 and the value of `collect-maximum-generation`, inclusive, and defaults to the value of `collect-maximum-generation`. 
As new data is allocated and collections occur, the storage-management system automatically requests additional virtual memory address space from the operating system. Correspondingly, in the event the heap shrinks significantly, the system attempts to return some of the virtual-memory previously obtained from the operating system back to the operating system. By default, the system attempts to do so only after a collection that targets the maximum nonstatic generation. The system can be asked to do so after collections targeting younger generations as well by altering the value \texttt{release-minimum-generation} to something less than the value of \texttt{collect-maximum-generation}. When the generation to which the parameter is set, or any older generation, is the target generation of a collection, the storage management system attempts to return unneeded virtual memory to the operating system following the collection.

When \texttt{collect-maximum-generation} is set to a new value \( g \), \texttt{release-minimum-generation} is implicitly set to \( g \) as well if (a) the two parameters have the same value before the change, or (b) \texttt{release-minimum-generation} has a value greater than \( g \).

\begin{itemize}
  \item \texttt{in-place-minimum-generation} \hspace{2cm} \texttt{global parameter} \\
  \hspace{2cm} \texttt{libraries: } \texttt{(chezscheme)}
\end{itemize}

This parameter determines when the storage-management system attempts to trade long-term space usage for the benefit of collection time and short-term space usage. When performing a collection at a generation at least as large as this parameter’s value, objects already residing at the generation are kept in place—unless the objects are in a memory region where previously keeping them in place resulted in too much fragmentation.

Typically, the value of \texttt{in-place-minimum-generation} should match the value of the \texttt{collect-maximum-generation} parameter, but the value of this parameter can be lower to move objects even less frequently, or it can be higher to disable attempts to keep otherwise mobile objects in place.

\begin{itemize}
  \item \texttt{heap-reserve-ratio} \hspace{2cm} \texttt{global parameter} \\
  \hspace{2cm} \texttt{libraries: } \texttt{(chezscheme)}
\end{itemize}

This parameter determines the approximate amount of memory reserved (not returned to the O/S as described in the entry for \texttt{release-minimum-generation}) in proportion to the amount currently occupied, excluding areas of memory that have been made static. Its value must be an inexact nonnegative flonum value; if set to an exact real value, the exact value is converted to an inexact value. The default value, 1.0, reserves one page of memory for each currently occupied nonstatic page. Setting it to a smaller value may result in a smaller average virtual memory footprint, while setting it to a larger value may result in fewer calls into the operating system to request and free memory space.

\begin{itemize}
  \item \texttt{(keep-live } v \texttt{)} \hspace{2cm} \texttt{procedure} \\
  \hspace{2cm} \texttt{returns: } \texttt{unspecified} \\
  \hspace{2cm} \texttt{libraries: } \texttt{(chezscheme)}
\end{itemize}

Ensures that the value produced by \( v \) is retained by the store manager until the \texttt{keep-live}
call is performed. This function can be particularly useful for ensuring that an immobile
object remains in place.

13.2. Weak Pairs, Ephemeron Pairs, and Guardians

Weak pairs allow programs to maintain weak pointers to objects. A weak pointer to an
object does not prevent the object from being reclaimed by the storage management system,
but it does remain valid as long as the object is otherwise accessible in the system.

Ephemeron pairs are like weak pairs, but ephemeron pairs combine two pointers where the
second is retained only as long as the first is retained.

Guardians allow programs to protect objects from deallocation by the garbage collector
and to determine when the objects would otherwise have been deallocated.

Weak pairs, ephemeron pairs, and guardians allow programs to retain information about
objects in separate data structures (such as hash tables) without concern that maintaining
this information will cause the objects to remain indefinitely in the system. Ephemeron
pairs allow such data structures to retain key–value combinations where a value may refer
to its key, but the combination can be reclaimed if neither must be saved otherwise. In
addition, guardians allow objects to be saved from deallocation indefinitely so that they
can be reused or so that clean-up or other actions can be performed using the data stored
within the objects.

The implementation of guardians and weak pairs used by Chez Scheme is described in [12].
Ephemeron pairs are described in [23], but the implementation in Chez Scheme avoids quadratic-
time worst-case behavior.

\[(\text{weak-cons } \text{obj}_1 \text{ obj}_2)\]

\underline{procedure}

returns: a new weak pair

libraries: (chezscheme)

\(\text{obj}_1\) becomes the car and \(\text{obj}_2\) becomes the cdr of the new pair. Weak pairs are indistin-
guishable from ordinary pairs in all but two ways:

- weak pairs can be distinguished from pairs using the \texttt{weak-pair?} predicate, and
- weak pairs maintain a weak pointer to the object in the car of the pair.

The weak pointer in the car of a weak pair is just like a normal pointer as long as the
object to which it points is accessible through a normal (nonweak) pointer somewhere in
the system. If at some point the garbage collector recognizes that there are no nonweak
pointers to the object, however, it replaces each weak pointer to the object with the “broken
weak-pointer” object, \#!bwp, and discards the object.

The \texttt{cdr} field of a weak pair is \textit{not} a weak pointer, so weak pairs may be used to form
lists of weakly held objects. These lists may be manipulated using ordinary list-processing
operations such as \texttt{length}, \texttt{map}, and \texttt{assv}. (Procedures like \texttt{map} that produce list structure
always produce lists formed from nonweak pairs, however, even when their input lists are
formed from weak pairs.) Weak pairs may be altered using \texttt{set-car!} and \texttt{set-cdr!}; after a
set-car! the car field contains a weak pointer to the new object in place of the old object. Weak pairs are especially useful for building association pairs in association lists or hash tables.

Weak pairs are printed in the same manner as ordinary pairs; there is no reader syntax for weak pairs. As a result, weak pairs become normal pairs when they are written and then read.

(define x (cons 'a 'b))
(define p (weak-cons x '()))
(car p) ⇒ (a . b)
(define x (cons 'a 'b))
(define p (weak-cons x '()))
(set! x '*)
(collect)
(car p) ⇒ #!bwp

The latter example above may in fact return (a . b) if a garbage collection promoting the pair into an older generation occurs prior to the assignment of x to *. It may be necessary to force an older generation collection to allow the object to be reclaimed. The storage management system guarantees only that the object will be reclaimed eventually once all nonweak pointers to it are dropped, but makes no guarantees about when this will occur.

(weak-pair? obj) procedure
returns: #t if obj is a weak pair, #f otherwise
libraries: (chezscheme)

(weak-pair? (weak-cons 'a 'b)) ⇒ #t
(weak-pair? (cons 'a 'b)) ⇒ #f
(weak-pair? "oops") ⇒ #f

(ephemeron-cons obj1 obj2) procedure
returns: a new ephemeron pair
libraries: (chezscheme)

obj1 becomes the car and obj2 becomes the cdr of the new pair. Ephemeron pairs are indistinguishable from ordinary pairs in all but two ways:

• ephemeron pairs can be distinguished from pairs using the ephemeron-pair? predicate, and
• ephemeron pairs maintain a weak pointer to the object in the car of the pair, and the cdr of the pair is preserved only as long as the car of the pair is preserved.

An ephemeron pair behaves like a weak pair, but the cdr is treated specially in addition to the car: the cdr of an ephemeron is set to #!bwp at the same time that the car is set to #!bwp. Since the car and cdr fields are set to #!bwp at the same time, then the fact that
the car object may be referenced through the cdr object does not by itself imply that car
must be preserved (unlike a weak pair); instead, the car must be saved for some reason
independent of the cdr object.

Like weak pairs and other pairs, ephemeron pairs may be altered using `set-car!` and
`set-cdr!`, and ephemeron pairs are printed in the same manner as ordinary pairs; there is
no reader syntax for ephemeron pairs.

```scheme
(define x (cons 'a 'b))
(define p (ephemeron-cons x x))
(car p) ⇒ (a . b)
(cdr p) ⇒ (a . b)

(define x (cons 'a 'b))
(define p (ephemeron-cons x x))
(set! x '*)
(collect)
(car p) ⇒ #!bwp
(cdr p) ⇒ #!bwp

(define x (cons 'a 'b))
(define p (weak-cons x x)); not an ephemeron pair
(set! x '*)
(collect)
(car p) ⇒ (a . b)
(cdr p) ⇒ (a . b)
```

As with weak pairs, the last two expressions of the middle example above may in fact
return `(a . b)` if a garbage collection promoting the pair into an older generation occurs
prior to the assignment of `x` to `*`. In the last example above, however, the results of the last
two expressions will always be `(a . b)`, because the cdr of a weak pair holds a non-weak
reference, and that non-weak reference prevents the car field from becoming `#!bwp`.

### (ephemeron-pair? obj) procedure
returns: `#t` if `obj` is a ephemeron pair, `#f` otherwise
libraries: `(chezscheme)`

```
(ephemeron-pair? (ephemeron-cons 'a 'b)) ⇒ #t
(ephemeron-pair? (cons 'a 'b)) ⇒ #f
(ephemeron-pair? (weak-cons 'a 'b)) ⇒ #f
(ephemeron-pair? "oops") ⇒ #f
```

### (bwp-object? obj) procedure
returns: `#t` if `obj` is the broken weak-pair object, `#f` otherwise
libraries: `(chezscheme)`

```
(bwp-object? #!bwp) ⇒ #t
(bwp-object? 'bwp) ⇒ #f
```
(define x (cons 'a 'b))
(define p (weak-cons x '()))
(set! x '*)
(collect (collect-maximum-generation))
(car p) ⇒ #!bwp
(bwp-object? (car p)) ⇒ #t

(make-guardian)                       procedure
(make-guardian ordered?)              procedure

returns: a new guardian that is unordered unless ordered? is true
libraries: (chezscheme)

Guardians are represented by procedures that encapsulate groups of objects registered for preservation. When a guardian is created, the group of registered objects is empty. An object is registered with a guardian by passing the object as an argument to the guardian:

(define G (make-guardian))
(define x (cons 'aaa 'bbb))
x ⇒ (aaa . bbb)
(G x)

It is also possible to specify a “representative” object when registering an object. Continuing the above example:

(define y (cons 'ccc 'ddd))
y ⇒ (ccc . ddd)
(G y 'rep)

The group of registered objects associated with a guardian is logically subdivided into two disjoint subgroups: a subgroup referred to as “accessible” objects, and one referred to “inaccessible” objects. Inaccessible objects are objects that have been proven to be inaccessible (except through the guardian mechanism itself or through the car field of a weak or ephemeron pair), and accessible objects are objects that have not been proven so. The word “proven” is important here: it may be that some objects in the accessible group are indeed inaccessible but that this has not yet been proven. This proof may not be made in some cases until long after the object actually becomes inaccessible (in the current implementation, until a garbage collection of the generation containing the object occurs).

Objects registered with a guardian are initially placed in the accessible group and are moved into the inaccessible group at some point after they become inaccessible. Objects in the inaccessible group are retrieved by invoking the guardian without arguments. If there are no objects in the inaccessible group, the guardian returns #f. Continuing the above example:

(G) ⇒ #f
(set! x #f)
(set! y #f)
(collect)
(G) ⇒ (aaa . bbb) ; this might come out second
13.2. Weak Pairs, Ephemeron Pairs, and Guardians

(G) ⇒ rep ; and this first
(G) ⇒ #f

The initial call to G returns #f, since the pairs bound to x and y are the only object registered with G, and the pairs are still accessible through those bindings. When collect is called, the objects shift into the inaccessible group. The two calls to G therefore return the pair previously bound to x and the representative of the pair previously bound to y, though perhaps in the other order from the one shown. (As noted above for weak pairs, the call to collect may not actually be sufficient to prove the object inaccessible, if the object has migrated into an older generation.)

Although an object registered without a representative and returned from a guardian has been proven otherwise inaccessible (except possibly via the car field of a weak or ephemeron pair), it has not yet been reclaimed by the storage management system and will not be reclaimed until after the last nonweak pointer to it within or outside of the guardian system has been dropped. In fact, objects that have been retrieved from a guardian have no special status in this or in any other regard. This feature circumvents the problems that might otherwise arise with shared or cyclic structure. A shared or cyclic structure consisting of inaccessible objects is preserved in its entirety, and each piece registered for preservation with any unordered guardian is placed in the inaccessible set for that guardian. The programmer then has complete control over the order in which pieces of the structure are processed.

An ordered guardian, as created by providing a true value for ordered?, treats an object as inaccessible only when it is not accessible from any representative of an object that is in any usable guardian’s inaccessible group and that is distinct from the object itself. Cycles among objects registered with ordered guardians can never become inaccessible unless the cycle is broken or some of the relevant guardians are dropped by the program, and each registered object’s representative (if different from the object) can contribute to such cycles. If an object is registered to an ordered guardian with a representative that is different from the object but that references the object, then the object is in a cycle and will not become inaccessible unless the reference from the representative to the object is destroyed. Weak references do not count, so objects that form a cycle only when counting weak references may still become inaccessible.

An object may be registered with a guardian more than once, in which case it will be retrievable more than once:

(define G (make-guardian))
(define x (cons ’aaa ’bbb))
(G x)
(G x)
(set! x #f)
(collect)
(G) ⇒ (aaa . bbb)
(G) ⇒ (aaa . bbb)

It may also be registered with more than one guardian, and guardians themselves can be registered with other guardians. If an object is registered to both an unordered guardian
and an ordered guardian and neither guardian is dropped, the object can become inac-
cessible for the ordered guardian only after it has been determined inaccessible for the
unordered guardian and then retrieved and dropped again by the program.

An object that has been registered with a guardian without a representative and placed in
the car field of a weak or ephemeron pair remains in the car field of the weak or ephemeron
pair until after it has been returned from the guardian and dropped by the program or
until the guardian itself is dropped.

```
(define G (make-guardian))
(define x (cons 'aaa 'bbb))
(define p (weak-cons x '()))
(G x)
(set! x #f)
(collect)
(set! y (G))
  y ⇒ (aaa . bbb)
(car p) ⇒ (aaa . bbb)
(set! y #f)
(collect 1)
(car p) ⇒ #!bwp
```

(The first collector call above would promote the object at least into generation 1, requiring
the second collector call to be a generation 1 collection. This can also be forced by invoking
`collect` several times.)

On the other hand, if a representative (other than the object itself) is specified, the guarded
object is dropped from the car field of the weak or ephemeron pair at the same time as the
representative becomes available from the guardian.

```
(define G (make-guardian))
(define x (cons 'aaa 'bbb))
(define p (weak-cons x '()))
(G x 'rep)
(set! x #f)
(collect)
(G) ⇒ rep
(car p) ⇒ #!bwp
```

The following example illustrates that the object is deallocated and the car field of the
weak pair set to `#!bwp` when the guardian itself is dropped:

```
(define G (make-guardian))
(define x (cons 'aaa 'bbb))
(define p (weak-cons x '()))
(G x)
(set! x #f)
(set! G #f)
(collect)
(car p) ⇒ #!bwp
```
The example below demonstrates how guardians might be used to deallocate external storage, such as storage managed by the C library “malloc” and “free” operations.

```
(define malloc
  (let ([malloc-guardian (make-guardian)])
    (lambda (size)
      ; first free any storage that has been dropped. to avoid long
      ; delays, it might be better to deallocate no more than, say,
      ; ten objects for each one allocated
      (let f ()
        (let ([x (malloc-guardian)])
          (when x
            (do-free x)
            (f))))
      ; then allocate and register the new storage
      (let ([x (do-malloc size)])
        (malloc-guardian x)
        x))))
```

do-malloc must return a Scheme object “header” encapsulating a pointer to the external storage (perhaps as an unsigned integer), and all access to the external storage must be made through this header. In particular, care must be taken that no pointers to the external storage exist outside of Scheme after the corresponding header has been dropped. do-free must deallocate the external storage using the encapsulated pointer. Both primitives can be defined in terms of foreign-alloc and foreign-free or the C-library “malloc” and “free” operators, imported as foreign procedures. (See Chapter 4.)

If it is undesirable to wait until malloc is called to free dropped storage previously allocated by malloc, a collect-request handler can be used instead to check for and free dropped storage, as shown below.

```
(define malloc)
  (let ([malloc-guardian (make-guardian)])
    (set! malloc
      (lambda (size)
        ; allocate and register the new storage
        (let ([x (do-malloc size)])
          (malloc-guardian x)
          x)))))
```

collect-request-handler
  (lambda ()
    ; first, invoke the collector
    (collect)
    ; then free any storage that has been dropped
    (let f ()
      (let ([x (malloc-guardian)])
        (when x
          (do-free x)
          (f)))))))
```
With a bit of refactoring, it would be possible to register the encapsulated foreign address as a representative with each header, in which do-free would take just the foreign address as an argument. This would allow the header to be dropped from the Scheme heap as soon as it becomes inaccessible.

Guardians can also be created via ftype-guardian, which supports reference counting of foreign objects.

```
(guardian? obj) procedure
returns: #t if obj is a guardian, #f otherwise
libraries: (chezscheme)
```

```
(guardian? (make-guardian)) ⇒ #t
(guardian? (ftype-guardian iptr)) ⇒ #t
(guardian? (lambda x x)) ⇒ #f
(guardian? "oops") ⇒ #f
```

```
(unregister-guardian guardian) procedure
returns: see below
libraries: (chezscheme)
```

unregister-guardian unregisters the as-yet unresurrected objects currently registered with the guardian, with one caveat.

The caveat, which applies only to threaded versions of Chez Scheme, is that objects registered with the guardian by other threads since the last garbage collection might not be unregistered. To ensure that all objects are unregistered in a multithreaded application, a single thread can be used both to register and unregister objects. Alternatively, an application can arrange to define a collect-request handler that calls unregister-guardian after it calls collect.

In any case, unregister-guardian returns a list containing each object (or its representative, if specified) that it unregisters, with duplicates as appropriate if the same object is registered more than once with the guardian. Objects already resurrected but not yet retrieved from the guardian are not included in the list but remain retrievable from the guardian.

In the current implementation, unregister-guardian takes time proportional to the number of unresurrected objects currently registered with all guardians rather than those registered just with the corresponding guardian.

The example below assumes no collections occur except for those resulting from explicit calls to collect.

```
(define g (make-guardian))
(define x (cons 'a 'b))
(define y (cons 'c 'd))
(g x)
(g x)
```
13.3. Locking Objects

All pointers from C variables or data structures to Scheme objects should generally be discarded before entry (or reentry) into Scheme. When this guideline cannot be followed, the object may be locked via `lock-object` or via the equivalent C library procedure `Slock_object` (Section 4.9).

```
(lock-object obj)
```

| returns | unspecified |
| libraries | (chezscheme) |

Locking an object prevents the storage manager from reclaiming or relocating the object. Locking should be used sparingly, as it introduces memory fragmentation and increases storage management overhead.

Locking can also lead to accidental retention of storage if objects are not unlocked. Objects may be unlocked via `unlock-object` or the equivalent C library procedure `Sunlock_object`.

Unlocking immediate values, such as fixnums, booleans, and characters, or objects that have been made static is unnecessary but harmless.

```
(unlock-object obj)
```

| returns | unspecified |
| libraries | (chezscheme) |

An object may be locked more than once by successive calls to `lock-object`, `Slock_object`, or both, in which case it must be unlocked by an equal number of calls to `unlock-object` or `Sunlock_object` before it is truly unlocked.

An object contained within a locked object, such as an object in the car of a locked pair, need not also be locked unless a separate C pointer to the object exists. That is, if the inner object is accessed only via an indirection of the outer object, it should be left unlocked so that the collector is free to relocate it during collection.

Unlocking immediate values, such as fixnums, booleans, and characters, or objects that have been made static is unnecessary and ineffective but harmless.
13. Storage Management

(locked-object? obj)
procedure
returns: #t if obj is locked, immediate, or static
libraries: (chezscheme)

This predicate returns true if obj cannot be relocated or reclaimed by the collector, including immediate values, such as fixnums, booleans, and characters, and objects that have been made static.

13.4. Immobile Objects

Like a locked object, an immobile object will not be relocated by the storage manager. Unlike a locked object, and immobile object will be reclaimed by the storage manager if it is unreachable. Foreign-callable code objects are immobile, as are objects allocated by functions that specifically create immobile objects.

(box-immobile obj)
procedure
returns: a box
libraries: (chezscheme)

Like box, but creates a box that will not be relocated in memory by the storage management system until it is reclaimed.

(make-immobile-vector n)
(make-immobile-vector n obj)
procedure
returns: a vector
libraries: (chezscheme)

Like make-vector, but creates a vector that will not be relocated in memory by the storage management system until it is reclaimed.

(make-immobile-bytevector n)
(make-immobile-bytevector n byte)
procedure
returns: a vector
libraries: (chezscheme)

Like make-bytevector, but creates a bytevector that will not be relocated in memory by the storage management system until it is reclaimed.

13.5. Phantom Bytevectors

A phantom bytevector represents memory that is allocated outside of the Scheme storage management system. A phantom bytevector itself uses a small amount of space, but it contains a length that reflects external allocation. Representing external allocation can be useful for reflecting memory consumption and triggering garbage-collection heuristics.
Based on consumption. For example, for a program that allocates external objects and frees through a guardian, representing the external object’s memory use can trigger earlier garbage collections when the external objects are large. A phantom bytevector can also reflect external allocation to tools like `compute-size`, since the length of a phantom bytevector is included in the result of `compute-size` for the phantom bytevector.

```
(make-phantom-bytevector n)  procedure
returns: a phantom bytevector
libraries: (chezscheme)
```


$n$ must be an exact nonnegative integer.

Creates a phantom bytevector that reflects $n$ bytes of external allocation.

The value $n$ must reflect actual allocation in the sense of consuming a portion of the process’s address space. Claiming significantly more bytes than are actually allocated introduces the possibility of overflow within the storage management system’s calculations.

```
(phantom-bytevector? obj)  procedure
returns: #t if obj is a phantom bytevector, #f otherwise
libraries: (chezscheme)
```

```
(phantom-bytevector? (make-phantom-bytevector 1024))  ⇒  #t
```

```
(phantom-bytevector-length pbv)  procedure
returns: the length of the phantom bytevector
libraries: (chezscheme)
```

$pbv$ must be a phantom bytevector.

Returns the number of bytes of external allocation that $pbv$ represents.

```
(phantom-bytevector-length (make-phantom-bytevector 1024))  ⇒  1024
```

```
(set-phantom-bytevector-length! pbv n)  procedure
returns: unspecified
libraries: (chezscheme)
```

$pbv$ must be a phantom bytevector, and $n$ must be an exact nonnegative integer.

Adjusts the allocation represented by $pbv$ to $n$ bytes. For example, when an externally allocated object represented by $pbv$ is deallocated, then $pbv$’s length should be set to 0.

```
(define pbv (make-phantom-bytevector 1024))
(phantom-bytevector-length pbv)  ⇒  1024
(set-phantom-bytevector-length! pbv 1)
(phantom-bytevector-length pbv)  ⇒  1
```
14. Expression Editor

When the expression editor (expeditor) is enabled as described in Section 2.2, it allows
the user to edit expressions entered into the system and move backwards and forwards
through a history of entered expressions. This chapter describes a set of parameters that
may be used to control various aspects of the expression editor’s behavior (Section 14.1),
a procedure for binding key sequences to editing commands (Section 14.2), the built-in
editing commands (Section 14.3), and mechanisms for creating new editing commands
(Section 14.4).
These mechanisms are available through the expression-editor module.

expression-editor  module
libraries: (chezscheme)

The expression-editor module exports a set of bindings for parameters and other pro-
cedures that can be used to modify how the expression editor interacts with the user,
including the particular keys used to invoke the various editing commands.

Basic use of the expression editor is described in Section 2.2

14.1. Expression Editor Parameters

ee-auto-indent  global parameter

The value of ee-auto-indent is a boolean value that determines whether the expression
editor indents expressions as they are entered. Its default value is #t.

ee-standard-indent  global parameter

The value of ee-standard-indent is a nonnegative fixnum value that determines the
amount (in single spaces) by which each expression is indented relative to the enclos-
ing expression, if not aligned otherwise by one of the indenter’s other heuristics, when
ee-auto-indent is true or when one of the indentation commands is invoked explicitly. It’s
default value is 2.
The value of **ee-auto-paren-balance** is a boolean value that determines whether the expression editor automatically corrects a close parenthesis or bracket, when typed, to match the corresponding open parenthesis or bracket, if any. Its default value is `#t`.

The value of **ee-flash-parens** is a boolean value that determines whether the expression editor briefly moves the cursor when an open or close parenthesis or bracket is typed to the matching close or open parenthesis or bracket (if any). Its default value is `#t`.

The value of **ee-paren-flash-delay** is a nonnegative fixnum value that determines the amount of time (in milliseconds) that the expression editor pauses when the cursor is moved to the matching parenthesis or bracket, if any, when a parenthesis or bracket is entered. The value is ignored if the **ee-flash-parens** is false. Its default value is 100.

The value of **ee-default-repeat** is a nonnegative fixnum value that determines the number of times the next command is repeated after the **ee-command-repeat** editing command (bound to `Esc^-U` by default) is used and not followed by a sequence of digits. Its default value is 4.

The value of **ee-noisy** is a boolean value that determines whether the expression editor emits a beep (bell) when an error occurs, such as an attempt to find the matching delimiter for a non-delimiter character. Its default value is `#f`.

The value of **ee-history-limit** is a nonnegative fixnum value that determines the number of history entries retained by the expression editor during and across sessions. Only the last (ee-history-limit) entries are retained.

The value of **ee-common-identifiers** is list of symbols that are considered common enough that they should appear early when one of the incremental identifier-completion editing commands is invoked. Its default value contains a few dozen entries. They are all more than a few characters long (under the theory that users will most likely type short ones out fully) and all would appear later than they likely should when incremental identifier-completion is used.
14.2. Key Binding

Key bindings are established via \texttt{ee-bind-key}. The default key bindings are described in Section 14.3.

\begin{verbatim}
(ee-bind-key key procedure) procedure
returns: unspecified
\end{verbatim}

The \texttt{ee-bind-key} procedure is used to add to or change the set of key bindings recognized by the expression editor. The \texttt{key} must be a character or string; if it is a string, it must have the following form.

\[ \langle \text{key-string} \rangle \rightarrow "\langle \text{key-char}\rangle^+" \]

where

\[ \langle \text{key-char} \rangle \rightarrow \backslash e \text{ (specifying an escape character) } \]
\[ \mid \wedge x \text{ (specifying control-x) } \]
\[ \mid \\backslash^* \text{ (specifying caret) } \]
\[ \mid \backslash\backslash\backslash \text{ (specifying back slash) } \]
\[ \mid \text{ plain char (any character other than } \backslash \text{ or } ^* \text{)} \]

Note that each double-backslash in the syntax actually denotes just one backslash in the string.

For example, the \texttt{key} "\backslash eX" represents the two-character sequence Escape-x, i.e., the “escape” key followed by the (capital) “X” key. Similarly, they \texttt{key} "\backslash e^X" represents the two-character sequence Escape-Control-x, i.e., the “escape” key followed by Control-X.

Character keys and string keys consisting of a single plain character always represent a single keystroke.

The \texttt{procedure} argument should normally be one of the built-in editing commands described below. It is also possible to define new editing commands with \texttt{ee-string-macro} and \texttt{ee-compose}.

14.3. Editing Commands

The editing commands are grouped into sections according to usage. Each is listed along with the default character sequence or sequences by which it may be invoked.

\textbf{Insertion commands}

\begin{verbatim}
command: ee-insert-self
key(s): most printing characters
\end{verbatim}

Inserts the entered character into the entry.
command: ee-insert-paren  
key(s): (, ), [, ]  
Inserts the entered parenthesis or bracket into the entry.  
If the parameter ee-auto-paren-balance is true, the editor corrects close delimiters if necessary to balance existing open delimiters, when a matching open delimiter can be found.  
If the parameter ee-flash-parens is true, the editor briefly moves the cursor to the matching delimiter, if one can be found, pausing for an amount of time controlled by the parameter ee-paren-flash-delay. If the matching delimiter is not presently displayed, the cursor is flashed to the upper-left or lower-left corner of the displayed portion of the entry, as appropriate.  
The behavior of this command is undefined if used for something other than a parenthesis or bracket.

command: ee-newline  
key(s): none  
Inserts a newline at the cursor position, moves to the next line, and indents that line if the parameter ee-auto-indent is true. Does nothing if the entry is empty. See also ee-newline/accept.

command: ee-open-line  
key(s): ^O  
Inserts a newline at the cursor position and indents the next line, but does not move to the next line.

command: ee-yank-kill-buffer  
key(s): ^Y  
Inserts the contents of the kill buffer, which is set by the deletion commands described below.

command: ee-yank-selection  
key(s): ^V  
Inserts the contents of the window system’s current selection or paste buffer. When running in a shell window under X Windows, this command requires that the DISPLAY environment variable be set to the appropriate display.

Cursor movement commands

command: ee-backward-char  
key(s): leftarrow, ^B  
Moves the cursor left one character.

command: ee-forward-char  
key(s): rightarrow, ^F
Moves the cursor right one character.

**command:** ee-next-line  
**key(s):** downarrow, `^N`  
Moves the cursor down one line (and to the left if necessary so that the cursor does not sit beyond the last possible position). If the cursor is at the end of the current entry, and the current entry has not been modified, this command behaves like `ee-history-fwd`.

**command:** ee-previous-line  
**key(s):** uparrow, `^P`  
Moves the cursor up one line (and to the left if necessary so that the cursor does not sit beyond the last possible position). If the cursor is at the top of the current entry, and the current entry has not been modified, this command behaves like `ee-history-bwd`.

**command:** ee-beginning-of-line  
**key(s):** home, `^A`  
Moves the cursor to the first character of the current line.

**command:** ee-end-of-line  
**key(s):** end, `^E`  
Moves the cursor to the right of the last character of the current line.

**command:** ee-beginning-of-entry  
**key(s):** escape-<  
Moves the cursor to the first character of the entry.

**command:** ee-end-of-entry  
**key(s):** escape->  
Moves the cursor to the right of the last character of the entry.

**command:** ee-goto-matching-delimiter  
**key(s):** escape-]  
Moves the cursor to the matching delimiter. Has no effect if the character under the cursor is not a parenthesis or bracket or if no matching delimiter can be found.

**command:** ee-flash-matching-delimiter  
**key(s):** `^]`  
Moves the cursor briefly to the matching delimiter, if one can be found, pausing for an amount of time controlled by the parameter `ee-paren-flash-delay`. If the matching delimiter is not presently displayed, the cursor is flashed to the upper-left or lower-left corner of the displayed portion of the entry, as appropriate.

**command:** ee-exchange-point-and-mark  
**key(s):** `^X`-`^X`
Moves the cursor to the mark and leaves the mark at the old cursor position. (The mark can be set with `ee-set-mark`.)

**command:** ee-forward-sexp  
**key(s):** escape-^F  
Moves the cursor to the start of the next expression.

**command:** ee-backward-sexp  
**key(s):** escape-^B  
Moves the cursor to the start of the preceding expression.

**command:** ee-forward-word  
**key(s):** escape-f, escape-F  
Moves the cursor to the end of the next word.

**command:** ee-backward-word  
**key(s):** escape-b, escape-B  
Moves the cursor to the start of the preceding word.

**command:** ee-forward-page  
**key(s):** pagedown, ^X-]  
Moves the cursor down one screen page.

**command:** ee-backward-page  
**key(s):** pageup, ^X-[  
Moves the cursor up one screen page.

**Deletion commands**

**command:** ee-delete-char  
**key(s):** delete  
Deletes the character under the cursor.  
See also `ee-eof/delete-char`.

**command:** ee-backward-delete-char  
**key(s):** backspace (rubout), ^H  
Deletes the character to the left of the cursor.

**command:** ee-delete-line  
**key(s):** ^U  
Deletes the contents of the current line, leaving behind an empty line. When used on the first line of a multiline entry of which only the first line is displayed, i.e., immediately after history movement, `ee-delete-line` deletes the contents of the entire entry, like `ee-delete-entry` (described below).
14.3. Editing Commands

**command:** ee-delete-to-eol  
**key(s):** ^K, escape-K  
If the cursor is at the end of a line, joins the line with the next line, otherwise deletes from the cursor position to the end of the line.

**command:** ee-delete-between-point-and-mark  
**key(s):** ^W  
Deletes text between the current cursor position and the mark. (The mark can be set with ee-set-mark.)

**command:** ee-delete-entry  
**key(s):** ^G  
Deletes the contents of the current entry.

**command:** ee-reset-entry  
**key(s):** ^C  
Deletes the contents of the current entry and moves to the end of the history.

**command:** ee-delete-sexp  
**key(s):** escape-^K, escape-delete  
Deletes the expression that starts under the cursor, or if no expression starts under the cursor, deletes up to the next expression.

**command:** ee-backward-delete-sexp  
**key(s):** escape-backspace (escape-rubout), escape-^H  
Deletes the expression to the left of the cursor.

**Identifier/filename completion commands**
These commands perform either identifier or filename completion. Identifier completion is performed outside of a string constant, and filename completion is performed within a string constant. (In determining whether the cursor is within a string constant, the expression editor looks only at the current line and so can be fooled by string constants that span multiple lines.)

**command:** ee-id-completion  
**key(s):** none  
Inserts the common prefix of possible completions of the identifier or filename immediately to the left of the cursor. Identifier completion is based on the identifiers defined in the interaction environment. When there is exactly one possible completion, the common prefix is the completion. This command has no effect if no filename or identifier prefix is immediately the left of the cursor or if the possible completions have no common prefix. If run twice in succession, a list of possible completions is displayed.

See also ee-id-completion/indent.
command: ee-next-id-completion
key(s): ^R
Inserts one of the possible completions of the identifier or filename immediately to the left of the cursor. Identifier completion is based on the identifiers defined in the interaction environment. If run twice or more in succession, this command cycles through all of the possible completions. The order is determined by the following heuristics: appearing first are identifiers whose names appear in the list value of the parameter ee-common-identifiers; appearing second are identifiers bound in the interaction environment but not bound in the scheme-environment (i.e., identifiers defined by the user), and appearing last are those in the scheme environment. Within the set of matches appearing in the ee-common-identifiers list, those listed earliest are shown first; the order is alphabetical within the other two sets.
See also ee-next-id-completion/indent.

History movement commands
The expression editor maintains a history of entries during each session. It also saves the history across sessions unless this behavior is disabled via the command-line argument "--eehistory off."
When moving from one history entry to another, only the first line of each multi-line entry is displayed. The redisplay command (which ^L is bound to by default) can be used to display the entire entry. It is also possible to move down one line at a time to expose just part of the rest of the entry.

command: ee-history-bwd
key(s): escape-uparrow, escape-^P
Moves to the preceding history entry if the current entry is empty or has not been modified; otherwise, has no effect.
See also ee-previous-line.

command: ee-history-fwd
key(s): escape-downarrow, escape-^N
Moves to the next history entry if the current entry is empty or has not been modified; otherwise, has no effect.
See also ee-next-line.

command: ee-history-bwd-prefix
key(s): escape-p
Moves to the closest previous history entry, if any, that starts with the sequence of characters that makes up the current entry. May be used multiple times to search for same prefix.

command: ee-history-fwd-prefix
key(s): escape-n
Moves to the closest following history entry, if any, that starts with the sequence of characters that makes up the current entry. May be used multiple times to search for same prefix.

**command:** ee-history-bwd-contains  
**key(s):** escape-P

Moves to the closest previous history entry, if any, that contains within it the sequence of characters that makes up the current entry. May be used multiple times to search for same content.

**command:** ee-history-fwd-contains  
**key(s):** escape-N

Moves to the closest following history entry, if any, that contains within it the sequence of characters that makes up the current entry. May be used multiple times to search for same content.

**Indentation commands**

**command:** ee-indent  
**key(s):** escape-tab

Re-indents the current line.  
See also ee-next-id-completion/indent.

**command:** ee-indent-all  
**key(s):** escape-q, escape-Q, escape-^Q

Re-indents each line of the entire entry.

**Miscellaneous commands**

**command:** ee-accept  
**key(s):** ^J

Causes the expression editor to invoke the Scheme reader on the contents of the entry. If the read is successful, the expression is returned to the waiter; otherwise, an error message is printed, the entry redisplayed, and the cursor left (if possible) at the start of the invalid subform.  
See also ee-newline/accept.

**command:** ee-eof  
**key(s):** none

Causes end-of-file to be returned from the expression editor, which in turn causes the waiter to exit. Ignored unless entry is empty.  
See also ee-eof/delete-char.

**command:** ee-redisplay  
**key(s):** ^L
Redisplays the current expression. If run twice in succession, clears the screen and redisplays the expression at the top of the screen.

**command:** `ee-suspend-process`  
**key(s):** `^Z`  
Suspends the current process in shells that support job control.

**command:** `ee-set-mark`  
**key(s):** `^0`, `space`  
Sets the mark to the current cursor position.

**command:** `ee-command-repeat`  
**key(s):** `escape-^U`  
Repeats the next command \( n \) times. If the next character typed is a digit, \( n \) is determined by reading up the sequence of the digits typed and treating it as a decimal number. Otherwise, \( n \) is the value of the parameter `ee-default-repeat`.

**Combination commands**

**command:** `ee-newline/accept`  
**key(s):** `enter`, `^M`  
Behaves like `ee-accept` if run at the end (not including whitespace) of an entry that starts with a balanced expression; otherwise, behaves like `ee-newline`.

**command:** `ee-id-completion/indent`  
**key(s):** `tab`  
Behaves like `ee-id-completion` if an identifier (outside a string constant) or filename (within a string constant) appears just to the left of the cursor and the last character of that identifier or filename was just entered; otherwise, behaves like `ee-indent`.

If an existing identifier or filename, i.e., not one just typed, appears to the left of the cursor, the first use of this command behaves like `ee-newline`, the second consecutive use behaves like `ee-id-completion`, and the third behaves like a second consecutive use of `ee-id-completion`.

**command:** `ee-next-id-completion/indent`  
**key(s):** `none`  
Behaves like `ee-next-id-completion` if an identifier (outside a string constant) or filename (within a string constant) appears just to the left of the cursor and the last character of that identifier or identifier was just entered; otherwise, behaves like `ee-indent`.

**command:** `ee-eof/delete-char`  
**key(s):** `^D`  
Behaves like `ee-delete-char` if the entry is nonempty; otherwise, behaves like `ee-eof`. If the entry is nonempty and this command is run twice or more in succession, it does nothing once the entry becomes empty. This is to prevent accidental exit from the waiter in cases
where the command is run repeatedly (perhaps with the help of a keyboard’s auto-repeat feature) to delete all of the characters in an entry.

14.4. Creating New Editing Commands

\[(ee\text{-}string\text{-}macro \text{string})\]

returns: a new editing command

The new editing command produced inserts \text{string} before the current cursor position.

Two string macros are predefined:

\[(ee\text{-}string\text{-}macro "\text{(define }) \text{)\) escape-d\)
\[(ee\text{-}string\text{-}macro "\text{(lambda }) \text{)\) escape-l\)

\[(ee\text{-}compose \text{ecmd } \ldots)\]

returns: a new editing command

Each \text{ecmd} must be an editing command.

The new editing command runs each of the editing commands \text{ecmd } \ldots in sequence.

For example, the following expression binds \^X-p to an editing command that behaves like \text{ee\text{-}history\text{-}bwd\text{-}prefix} but leaves the cursor at the end of the expression rather than at the end of the first line, causing the entire entry to be displayed.

\[
(\text{let} ()
  (\text{import} \text{expression\text{-}editor})
  (\text{ee\text{-}bind\text{-}key } "\text{Xp}"
    (\text{ee\text{-}compose} \text{ee\text{-}history\text{-}bwd} \text{ee\text{-}end\text{-}of\text{-}entry})))
\]

A command such as \text{ee\text{-}id\text{-}completion} that performs a different action when run twice in succession will not recognize that it has been run twice in succession if run as part of a composite command.
15. Thread System

This chapter describes the Chez Scheme thread-system procedures and syntactic forms. With the exception of locks, locked increment, and locked decrement, the features of the thread system are implemented on top of the Posix thread system (pthreads) on non-Windows-based system and directly using the Windows API on Windows-based systems. Consult the appropriate documentation on your system for basic details of thread creation and interaction.

Most primitive Scheme procedures are thread-safe, meaning that they can be called concurrently from multiple threads. This includes allocation operations like cons and make-string, accessors like car and vector-ref, numeric operators like + and sqrt, and nondestructive higher-level primitive operators like append and map.

Simple mutation operators, like set-car!, vector-set!, and record field mutators are thread-safe. Likewise, assignments to local variables, including assignments to (unexported) library and top-level program variables are thread-safe.

Other destructive operators are thread safe only if they are used to operate on different objects from those being read or modified by other threads. For example, assignments to global variables are thread-safe only as long as one thread does not assign the same variable another thread references or assigns. Similarly, putprop can be called in one thread while another concurrently calls putprop or getprop if the symbols whose property lists are being modified or accessed differ.

In this context, most I/O operations should be considered destructive, since they might modify a port’s internal structure; see also Section 15.9 for information on buffered ports.

Use of operators that are not thread-safe without proper synchronization can corrupt the objects upon which they operate. This corruption can lead to incorrect behavior, memory faults, and even unrecoverable errors that cause the system to abort.

The compiler and interpreter are thread-safe to the extent that user code evaluated during the compilation and evaluation process is thread-safe or properly synchronized. Thus, two or more threads can call any of the compiler or interpreter entry points, i.e., compile, compile-file, compile-program, compile-script, compile-port, or interpret at the same time. Naturally, the object-file targets of two file compilation operations that run at the same time should be different. The same is true for eval and load as long as the default evaluator is used or is set explicitly to compile, interpret, or some other thread-safe evaluator.

One restriction should be observed when one of multiple threads creates or loads compiled
code, however, which is that only that thread or subsequently created children, or children
of subsequently created children, etc., should run the code. This is because multiple-
processor systems upon which threaded code may run might not guarantee that the data
and instruction caches are synchronized across processors.

15.1. Thread Creation

(fork-thread thunk) procedure
returns: a thread object
libraries: (chezscheme)

*thunk* must be a procedure that accepts zero arguments.

(fork-thread thunk) invokes *thunk* in a new thread and returns a thread object.

Threads created by foreign code using some means other than *fork-thread* must call
Sactivate_thread (Section 4.9) before touching any Scheme data or calling any Scheme
procedures.

(thread-join thread) procedure
returns: unspecified
libraries: (chezscheme)

Waits until *thread* has completed.

(get-initial-thread) procedure
returns: a thread object for the initial thread
libraries: (chezscheme)

(thread? obj) procedure
returns: #t if *obj* is a thread object, #f otherwise
libraries: (chezscheme)

(get-thread-id) procedure
returns: the thread id of the current thread
libraries: (chezscheme)

The thread id is a thread number assigned by thread id, and has no relationship to the
process id returned by get-process-id, which is the same in all threads.

(thread-preserve-ownership!) procedure
(thread-preserve-ownership! thread) procedure
returns: unspecified
libraries: (chezscheme)

Provides a hint to the storage manager that *thread* (which defaults to the current thread if
not supplied) can particularly benefit from tracking the objects that it allocates for parallel collection.

15.2. Mutexes

\[(\text{make-mutex} \ \text{name})\]

returns: a new mutex object

libraries: (chezscheme)

\text{name}, if supplied, must be a symbol which identifies the mutex, or \#f for no name. The name is printed every time the mutex is printed, which is useful for debugging.

\[(\text{mutex?} \ \text{obj})\]

returns: \#t if \text{obj} is a mutex, \#f otherwise

libraries: (chezscheme)

\[(\text{mutex-acquire} \ \text{mutex})\]

\[(\text{mutex-acquire} \ \text{mutex} \ \text{block?})\]

returns: see below

libraries: (chezscheme)

\text{mutex} must be a mutex.

\text{mutex-acquire} acquires the mutex identified by \text{mutex}. The optional boolean argument \text{block?} defaults to \#t and specifies whether the thread should block waiting for the mutex. If \text{block?} is omitted or is true, the thread blocks until the mutex has been acquired, and an unspecified value is returned.

If \text{block?} is false and the mutex currently belongs to a different thread, the current thread does not block. Instead, \text{mutex-acquire} returns immediately with the value \#f to indicate that the mutex is not available. If \text{block?} is false and the mutex is successfully acquired, \text{mutex-acquire} returns \#t.

Mutexes are recursive in Posix threads terminology, which means that the calling thread can use \text{mutex-acquire} to (re)acquire a mutex it already has. In this case, an equal number of \text{mutex-release} calls is necessary to release the mutex.

\[(\text{mutex-release} \ \text{mutex})\]

returns: unspecified

libraries: (chezscheme)

\text{mutex} must be a mutex.

\text{mutex-release} releases the mutex identified by \text{mutex}. Unpredictable behavior results if the mutex is not owned by the calling thread.
(with-mutex mutex body1 body2 ...) syntax
returns: the values of the body body1 body2 ...
libraries: (chezscheme)

with-mutex evaluates the expression mutex, which must evaluate to a mutex, acquires the mutex, evaluates the body body1 body2 ..., and releases the mutex. The mutex is released whether the body returns normally or via a control operation (that is, throw to a continuation, perhaps because of an error) that results in a nonlocal exit from the with-mutex form. If control subsequently returns to the body via a continuation invocation, the mutex is reacquired.

Using with-mutex is generally more convenient and safer than using mutex-acquire and mutex-release directly.

(mutex-name mutex) procedure
returns: the name associated with mutex, if any; otherwise #f
libraries: (chezscheme)

mutex must be a mutex.

15.3. Conditions

(make-condition) procedure
(make-condition name) procedure
returns: a new condition object
libraries: (chezscheme)

name, if supplied, must be a symbol which identifies the condition object, or #f for no name. The name is printed every time the condition is printed, which is useful for debugging.

(thread-condition? obj) procedure
returns: #t if obj is a condition object, #f otherwise
libraries: (chezscheme)

(condition-wait cond mutex) procedure
(condition-wait cond mutex timeout) procedure
returns: #t if the calling thread was awakened by the condition, #f if the calling thread timed out waiting
libraries: (chezscheme)

cond must be a condition object, and mutex must be a mutex. The optional argument timeout is a time record of type time-duration or time-utc, or #f for no timeout. It defaults to #f.

condition-wait waits up to the specified timeout for the condition identified by the condition object cond. The calling thread must have acquired the mutex identified by the
mutex `mutex` at the time `condition-wait` is called. `mutex` is released as a side effect of the call to `condition-wait`. When a thread is later released from the condition variable by one of the procedures described below or the timeout expires, `mutex` is reacquired and `condition-wait` returns.

```scheme
(condition-signal cond) procedure
returns: unspecified
libraries: (chezscheme)
```

`cond` must be a condition object.

`condition-signal` releases one of the threads waiting for the condition identified by `cond`.

```scheme
(condition-broadcast cond) procedure
returns: unspecified
libraries: (chezscheme)
```

`cond` must be a condition object.

`condition-broadcast` releases all of the threads waiting for the condition identified by `cond`.

```scheme
(condition-name condition) procedure
returns: the name associated with `condition`, if any; otherwise #f
libraries: (chezscheme)
```

`condition` must be a condition.

## 15.4. Locks

Locks are more primitive but more flexible and efficient than mutexes and can be used in situations where the added mutex functionality is not needed or desired. They can also be used independently of the thread system (including in nonthreaded versions of Chez Scheme) to synchronize operations running in separate Scheme processes as long as the lock is allocated in memory shared by the processes.

A lock is simply a word-sized integer, i.e., an `ipt` or `upt` foreign type (Section 4.5) with the native endianness of the target machine, possibly part of a larger structure defined using `define-ftype` (page 77). It must be explicitly allocated in memory that resides outside the Scheme heap and, when appropriate, explicitly deallocated. When just threads are involved (i.e., when multiple processes are not involved), the memory can be allocated via `foreign-alloc`. When multiple processes are involved, the lock should be allocated in some area shared by the processes that will interact with the lock.

Once initialized using `ftype-init-lock!`, a process or thread can attempt to lock the lock via `ftype-lock!` or `ftype-spin-lock!`. Once the lock has been locked and before it is unlocked, further attempts to lock the lock fail, even by the process or thread that most
recently locked it. Locks can be unlocked, via \texttt{ftype-unlock!}, by any process or thread, not just by the process or thread that most recently locked the lock.

The lock mechanism provides little structure, and mistakes in allocation and use can lead to memory faults, deadlocks, and other problems. Furthermore, no memory ordering is implied by a lock operation, which means that \texttt{memory-order-acquire} and \texttt{memory-order-release} may be needed to complete the intended synchronization of a lock. Thus, it is usually advisable to use locks only as part of a higher-level abstraction that ensures locks are used in a disciplined manner.

\begin{verbatim}
(define lock
  (make-ftype-pointer uptr
    (foreign-alloc (ftype-sizeof uptr))))

(ftype-init-lock! uptr () lock)
(ftype-lock! uptr () lock) ⇒ #t, assuming no spurious failure
(ftype-lock! uptr () lock) ⇒ #f
(ftype-unlock! uptr () lock)
(ftype-spin-lock! uptr () lock)
(ftype-lock! uptr () lock) ⇒ #f
(ftype-unlock! uptr () lock)

(ftype-init-lock! ftype-name (a ...) fptr-expr)
(ftype-init-lock! ftype-name (a ...) fptr-expr index) syntax
returns: unspecified

(ftype-lock! ftype-name (a ...) fptr-expr)
(ftype-lock! ftype-name (a ...) fptr-expr index) syntax
returns: #t if the lock is not already locked, #f otherwise

(ftype-spin-lock! ftype-name (a ...) fptr-expr)
(ftype-spin-lock! ftype-name (a ...) fptr-expr index) syntax
returns: unspecified

(ftype-unlock! ftype-name (a ...) fptr-expr)
(ftype-unlock! ftype-name (a ...) fptr-expr index) syntax
returns: unspecified

libraries: (chezscheme)
\end{verbatim}

Each of these has a syntax like and behaves similarly to \texttt{ftype-set!} (page 86), though with an implicit \texttt{val-expr}. In particular, the restrictions on and handling of \texttt{fptr-expr} and the accessors \texttt{a ...} is similar, with one important restriction: the field specified by the last accessor, upon which the form operates, must be a word-size integer, i.e., an \texttt{iptr}, \texttt{uptr}, or the equivalent, with the native endianness.

\texttt{ftype-init-lock!} should be used to initialize the lock prior to the use of any of the other operators; if this is not done, the behavior of the other operators is undefined.

\texttt{ftype-lock!} can be used to lock the lock. If it finds the lock unlocked at the time of the operation, it (normally) locks the lock and returns \#t; if it finds the lock already locked, it returns \#f without changing the lock. On an architecture with a weak memory model, \texttt{ftype-lock!} can spuriously fail, leaving a lock unchanged and returning \#f even if the
15.5. Locked increment and decrement

lock is currently unlocked. On success, no memory ordering is implied, which means that memory-order-acquire may be needed to complete an intended synchronization.

ftype-spin-lock! can also be used to lock the lock. If it finds the lock unlocked at the time of the operation, it locks the lock and returns; if it finds the lock already locked, it waits until the lock is unlocked, then locks the lock and returns. If no other thread or process unlocks the lock, the operation does not return and cannot be interrupted by normal means, including by the storage manager for the purpose of initiating a garbage collection. There are also no guarantees of fairness, so a process might hang indefinitely even if other processes are actively locking and unlocking the lock.

ftype-unlock! is used to unlock a lock. If it finds the lock locked, it unlocks the lock and returns. Otherwise, it returns without changing the lock. On an architecture with a weak memory model, no memory ordering is implied, and memory-order-release may be needed to complete an intended synchronization.

15.5. Locked increment and decrement

The locked operations described here can be used when just an atomic increment or decrement is required.

(ftype-locked-incr! ftype-name (a ...) fptr-expr) syntax
(ftype-locked-incr! ftype-name (a ...) fptr-expr index) syntax
returns: #t if the updated value is 0, #f otherwise

(ftype-locked-decr! ftype-name (a ...) fptr-expr) syntax
(ftype-locked-decr! ftype-name (a ...) fptr-expr index) syntax
returns: #t if the updated value is 0, #f otherwise

libraries: (chezscheme)

Each of these has a syntax like and behaves similarly to ftype-set! (page 86), though with an implicit val-expr. In particular, the restrictions on and handling of fptr-expr and the accessors a ... is similar, with one important restriction: the field specified by the last accessor, upon which the form operates, must be a word-size integer, i.e., an iptr, uptr, or the equivalent, with the native endianness.

ftype-locked-incr! atomically reads the value of the specified field, adds 1 to the value, and writes the new value back into the field. Similarly, ftype-locked-decr! atomically reads the value of the specified field, subtracts 1 from the value, and writes the new value back into the field. Both return #t if the new value is 0, otherwise #f.

15.6. Reference counting with ftype guardians

Applications that manage memory outside the Scheme heap can leverage the Scheme storage management system to help perform reference counting via ftype guardians. In a reference-counted memory management system, each object holds a count of pointers to it.
The count is incremented when a new pointer is created and decremented when a pointer is dropped. When the count reaches zero, the object is no longer needed and the memory it formerly occupied can be made available for some other purpose.

Ftype guardians are similar to guardians created by make-guardian (Section 13.2). The guardian? procedure returns true for both, and the unregister-guardian procedure can be used to unregister objects registered with either.

(fctype-guardian ftype-name) syntax
returns: a new ftype guardian
libraries: (chezscheme)

ftype-name must name an ftype. The first base field of the ftype (or one of the first base fields in the case of unions) must be a word-sized integer (iptr or uptr) with native endianness. This field is assumed to hold a reference count.

The return value is a new ftype guardian g, with which ftype-pointers of type ftype-name (or some subtype of ftype-name) can be registered. An ftype pointer is registered with g by invoking g with the ftype pointer as an argument.

An ftype guardian does not automatically protect from collection the ftype pointers registered with it, as a normal guardian would do. Instead, for each registered ftype pointer that becomes inaccessible via normal (non-weak, non-guardian pointers), the guardian decrements the reference count of the object to which the ftype pointer points. If the resulting reference-count value is zero, the ftype pointer is preserved and can be retrieved from the guardian. If the resulting reference-count value is non-zero, however, the ftype pointer is not preserved. Objects retrieved from an ftype guardian (by calling it without arguments) are guaranteed to have zero reference counts, assuming reference counts are maintained properly by code outside the collector.

The collector decrements the reference count using the equivalent of ftype-locked-decr! to support systems in which non-Scheme objects are stored in memory shared by multiple processes. In such systems, programs should themselves use ftype-locked-incr! and ftype-locked-decr! or non-Scheme equivalents (e.g., the C LOCKED_INCR and LOCKED_DECR macros in scheme.h, which are described in Section 4.9) to maintain reference counts.

The following example defines a simple ftype and an allocator for objects of that ftype that frees any objects of that ftype that were previously allocated and no longer accessible.

(module (A make-A free-dropped-As)
  (define-ftype A
    (struct
      [refcount uptr]
      [data int]))
  (define g (fctype-guardian A))
  (define free-dropped-As
    (lambda ()
      (let ([a (g)])
        (when a
          (printf "freeing ~s\n" (ftype-ref A (data) a))
          (foreign-free (ftype-pointer-address a))))
    (lambda ()
      (let ([a (g)])
        (when a
          (printf "freeing ~s\n" (ftype-ref A (data) a))
          (foreign-free (ftype-pointer-address a))))

474 15. Thread System
(define make-A
(lambda (n)
  (let ([a (make-ftype-pointer A (foreign-alloc (ftype-sizeof A)))]
    (ftype-set! A (refcount) a 1)
    (ftype-set! A (data) a n)
    (g a)
    a)))))

We can test this by allocating, dropping, and immediately collecting ftype pointers to A.

> (do ([i 10 (fx- i 1)])
    ((fx= i 0))
    (make-A i)
    (collect))
freeing 10
freeing 9
freeing 8
freeing 7
freeing 6
freeing 5
freeing 4
freeing 3
freeing 2
> (free-dropped-As)
freeing 1

Objects guarded by an ftype guardian might contain pointers to other objects whose reference counts should also be incremented upon allocation of the containing object and decremented upon freeing of the containing object.

15.7. Memory Consistency

Scheme threads can expose the memory-consistency model of the underlying processor, except to the degree that it would interfere with the memory safety of Scheme programs. For example, if two threads share a vector, then a \texttt{vector-set!} in one thread will not allow the other thread to read the vector and see a partially constructed primitive object installed into the vector; the Scheme system includes a memory fence around operations and on platforms as needed to preserve safety. There’s no guarantee, for example, that assigning to multiple slots in an \texttt{fxvector} will become visible in the same order to other threads that share the vector, because no such ordering is required to preserve memory safety.
These procedures fence memory operations in a way that is consistent with acquire–release patterns. Specifically, `memory-order-acquire` ensures at least a load–load and load–store fence, and `memory-order-release` ensures at least a store–store and store–load fence.

### 15.8. Thread Parameters

See Section [12.13](#) for a general discussion of parameters and the use of the optional second argument.

When a thread parameter is created, a separate location is set aside in each current and future thread to hold the value of the parameter’s internal state variable. (This location may be eliminated by the storage manager when the parameter becomes inaccessible.) Changes to the thread parameter in one thread are not seen by any other thread.

When a new thread is created (see `fork-thread`), the current value (not location) of each thread parameter is inherited from the forking thread by the new thread. Similarly, when a thread created by some other means is activated for the first time (see `Sactivate_thread` in Section [4.9](#)), the current value (not location) of each thread parameter is inherited from the main (original) thread by the new thread.

Most built-in parameters are thread parameters, but some are global. All are marked as global or thread where they are defined. There is no distinction between built-in global and thread parameters in the nonthreaded versions of the system.

### 15.9. Buffered I/O

Chez Scheme buffers file I/O operations for efficiency, but buffered I/O is not thread safe. Two threads that write to or read from the same buffered port concurrently can corrupt the port, resulting in buffer overruns and, ultimately, invalid memory references.

Buffering on binary output ports can be disabled when opened with buffer-mode `none`. Buffering on input ports cannot be completely disabled, however, due to the need to support lookahead, and buffering on textual ports, even textual output ports, cannot be disabled completely because the transcoders that convert between characters and bytes sometimes require some lookahead.

Two threads should thus never read from or write to the same port concurrently, except in the special case of a binary output port opened buffer-mode `none`. Alternatives include
appointing one thread to perform all I/O for a given port and providing a per-thread
generic-port wrapper that forwards requests to the port only after acquiring a mutex.
The initial console and current input and output ports are thread-safe, as are transcript
ports, so it is safe for multiple threads to print error and/or debugging messages to the
console. The output may be interleaved, even within the same line, but the port will
not become corrupted. Thread safety for these ports is accomplished at the high cost of
acquiring a mutex for each I/O operation.

15.10. Example: Bounded Queues

The following code, taken from the article “A Scheme for native threads [10],” implements
a bounded queue using many of the thread-system features. A bounded queue has a fixed
number of available slots. Attempting to enqueue when the queue is full causes the calling
thread to block. Attempting to dequeue from an empty queue causes the calling thread to
block.

```
(define-record-type bq
  (fields
   (immutable data)
   (mutable head)
   (mutable tail)
   (immutable mutex)
   (immutable ready)
   (immutable room))
  (protocol
   (lambda (new)
    (lambda (bound)
      (new (make-vector bound) 0 0 (make-mutex)
           (make-condition) (make-condition))))))

(define dequeue!
  (lambda (q)
    (with-mutex (bq-mutex q)
      (let loop ()
        (let ([head (bq-head q)])
          (cond
           [(= head (bq-tail q))
            (condition-wait (bq-ready q) (bq-mutex q))
            (loop)]
           [else
            (bq-head-set! q (incr q head))
            (condition-signal (bq-room q))
            (vector-ref (bq-data q) head)]))))))

(define enqueue!
  (lambda (item q)
    (with-mutex (bq-mutex q)
      (let loop ()
        (let ([head (bq-head q)])
          (cond
           [(= head (bq-tail q))
            (condition-wait (bq-ready q) (bq-mutex q))
            (loop)]
           [else
            (bq-head-set! q (incr q head))
            (condition-signal (bq-room q))
            (vector-ref (bq-data q) head)]))))))
```
(let* ([tail (bq-tail q)] [tail^ (incr q tail)])
  (cond
   [(= tail^ (bq-head q))
    (condition-wait (bq-room q) (bq-mutex q))
    (loop)]
   [else
    (vector-set! (bq-data q) tail item)
    (bq-tail-set! q tail^)
    (condition-signal (bq-ready q))])))

(define incr
  (lambda (q i)
    (modulo (+ i 1) (vector-length (bq-data q))))))

The code below demonstrates the use of the bounded queue abstraction with a set of threads that act as consumers and producers of the data in the queue.

(define job-queue)
(define die? #f)

(define make-job
  (let ([count 0])
    (define fib
      (lambda (n)
        (if (< n 2)
            n
            (+ (fib (- n 2)) (fib (- n 1))))))
    (lambda (n)
      (set! count (+ count 1))
      (printf "Adding job #~s = (lambda () (fib ~s))\n" count n)
      (cons count (lambda () (fib n))))))

(define make-producer
  (lambda (n)
    (rec producer
      (lambda ()
        (printf "producer ~s posting a job\n" n)
        (enqueue! (make-job (+ 20 (random 10))) job-queue)
        (if die?
            (printf "producer ~s dying\n" n)
            (producer))))))

(define make-consumer
  (lambda (n)
    (rec consumer
      (lambda ()
        (printf "consumer ~s looking for a job-\n" n)
        (let ([job (dequeue! job-queue)])
          (if die?
              (printf "consumer ~s dying\n" n)
              (begin

```
(printf "consumer -s executing job #s-%n (car job))
(printf "consumer -s computed: -s-%n ((cdr job)))
(consumer)))))))))

(define (bq-test np nc)
  (set! job-queue (make-bq (max nc np)))
  (do ([np np (- np 1)])
      ((<= np 0))
    (fork-thread (make-producer np)))
  (do ([nc nc (- nc 1)])
      ((<= nc 0))
    (fork-thread (make-consumer nc))))

Here are a possible first several lines of output from a sample run of the example program.

> (begin
   (bq-test 3 4)
   (system "sleep 3")
   (set! die? #t))
producer 3 posting a job
Adding job #1 = (lambda () (fib 29))
producer 3 posting a job
Adding job #2 = (lambda () (fib 26))
producer 3 posting a job
Adding job #3 = (lambda () (fib 22))
producer 3 posting a job
Adding job #4 = (lambda () (fib 21))
producer 2 posting a job
Adding job #5 = (lambda () (fib 29))
producer 1 posting a job
Adding job #6 = (lambda () (fib 29))
consumer 4 looking for a job
producer 3 posting a job
Adding job #7 = (lambda () (fib 24))
consumer 4 executing job #1
consumer 3 looking for a job
producer 2 posting a job
Adding job #8 = (lambda () (fib 26))
consumer 3 executing job #2
consumer 3 computed: 121393
consumer 3 looking for a job
producer 1 posting a job
Adding job #9 = (lambda () (fib 26))
...

Additional examples, including definitions of suspendable threads and threads that automatically terminate when they become inaccessible, are given in “A Scheme for native threads [10].”
16. Compatibility Features

This chapter describes several items that are included with current versions of Chez Scheme primarily for compatibility with older versions of the system.

Section 16.1 describes a hash-table interface that has since been replaced by the R6RS hashtable interface. Section 16.2 describes extend-syntax macros. These features are supported directly by current versions of Chez Scheme, but support may be dropped in future versions. New programs should use the standard mechanisms described in The Scheme Programming Language, 4th Edition [11] instead.

Section 16.3 describes a mechanism for defining record-like structures as vectors instead of new unique types. New programs should use define-record, which is described in Section 7.17 instead.

Section 16.4 describes a compatibility file distributed with Chez Scheme that contains definitions for forms and procedures no longer supported directly by Chez Scheme.

16.1. Hash Tables

The hash table procedures here are obviated by the new hash table procedures listed in Section 7.14.

(make-hash-table) procedure
(make-hash-table weak?) procedure
returns: a new hash table
libraries: (chezscheme)

If weak? is provided and is non-false, the hash table is a weak hash table, which means that it does not protect keys from the garbage collector. Keys reclaimed by the garbage collector are removed from the table, and their associated values are dropped the next time the table is modified, if not sooner.

(hash-table? obj) procedure
returns: #t if obj is a hash table, otherwise #f
libraries: (chezscheme)
(put-hash-table! ht k v)  
returns: unspecified  
libraries: (chezscheme)

ht must be a hash table. k and v may be any Scheme values.
put-hash-table! associates the value v with the key k in ht.

(get-hash-table ht k d)  
returns: see below  
libraries: (chezscheme)

get-hash-table returns the value associated with k in ht. If no value is associated with k in ht, get-hash-table returns d.
Key comparisons are performed with eq?.
Because objects may be moved by the garbage collector, get-hash-table may need to rehash some objects and therefore cause side effects in the hash table. Thus, it is not safe to perform concurrent accesses of the same hash table from multiple threads using get-hash-table.

(remove-hash-table! ht k)  
returns: unspecified  
libraries: (chezscheme)

remove-hash-table! drops any association for k from ht.

(hash-table-map ht p)  
returns: see below  
libraries: (chezscheme)

hash-table-map applies p to each key, value association in ht, in no particular order, and returns a list of the resulting values, again in no particular order. p should accept two arguments, a key and a value.

(hash-table-for-each ht p)  
returns: unspecified  
libraries: (chezscheme)

hash-table-for-each applies p to each key, value association in ht, in no particular order. Unlike hash-table-map, it does not create a list of the values; instead, it’s value is unspecified. p should accept two arguments, a key and a value.
16.2. Extend-Syntax Macros

This section describes extend-syntax, a powerful yet easy to use syntactic extension facility based on pattern matching \[27\]. Syntactic transformations written using extend-syntax are similar to those written using a define-syntax with syntax-case, except that the transformations produced by extend-syntax do not automatically respect lexical scoping.

It is not typically possible to mix syntactic abstractions written using syntax-case with those written using extend-syntax seamlessly; it is generally preferable to use one or the other wherever possible. Support for extend-syntax within the syntax-case expander is provided only as an aid to migrating to syntax-case.

\[
(\text{extend-syntax} \ (\text{name} \ \text{key} \ \ldots) \ (\text{pat} \ \text{fender} \ \text{template}) \ \ldots) \ \text{syntax}
\]

returns: unspecified
libraries: (chezscheme)

The identifier name is the name, or syntax keyword, for the syntactic extension to be defined. When the system expander processes any list expression whose car is name, the syntactic transformation procedure generated by extend-syntax is invoked on this expression. The remaining identifiers key \ldots are additional keywords to be recognized within input expressions during expansion (such as else in cond or case).

Each clause after the list of keys consists of a pattern pat, an optional fender, and a template. The optional fender is omitted more often than not. The pat specifies the syntax the input expression must have for the clause to be chosen. Identifiers within the pattern that are not keywords (pattern variables) are bound to corresponding pieces of the input expression. If present, the fender is a Scheme expression that specifies additional constraints on the input expression (accessed through the pattern variables) that must be satisfied in order for the clause to be chosen. The template specifies what form the output takes, usually in terms of the pattern variables.

During expansion, the transformation procedure extend-syntax generates attempts to match the input expression against each pattern in the order the clauses are given. If the input expression matches the pattern, the pattern variables are bound to the corresponding pieces of the input expression and the fender for the clause, if any, is evaluated. If the fender returns a true value, the given expansion is performed. If input does not match the pattern or if the fender returns a false value, the transformation procedure tries the next clause. An exception is raised with condition type &assertion if no clause can be chosen.

Within the pattern, ellipsis (\ldots) may be used to specify zero or more occurrences of the preceding pattern fragment, or prototype. Similarly, ellipses may be used in the output to specify the construction of zero or more expansion prototypes. In this case, the expansion prototype must contain part of an input pattern prototype. The use of patterns, templates, ellipses within patterns and templates, and fenders is illustrated in the following sequence of examples.

The first example, defining rec, uses a single keyword, a single clause with no fender, and no ellipses.
The second example, defining \texttt{when}, shows the use of ellipses.

\begin{verbatim}
(extend-syntax (when)
  [((when test exp1 exp2 ...) (if test (begin exp1 exp2 ...) #f))])
\end{verbatim}

The next example shows the definition of \texttt{let}. The definition of \texttt{let} shows the use of multiple ellipses, employing one for the identifier/value pairs and one for the expressions in the body. It also shows that the prototype need not be a single identifier, and that pieces of the prototype may be separated from one another in the template.

\begin{verbatim}
(extend-syntax (let)
  [(let ([x e] ...) b1 b2 ...)
   ((lambda (x ...) b1 b2 ...) e ...)])
\end{verbatim}

The next example shows \texttt{let*}, whose syntax is the same as for \texttt{let}, but which is defined recursively in terms of \texttt{let} with two clauses (one for the base case, one for the recursion step) since it must produce a nested structure.

\begin{verbatim}
(extend-syntax (let*)
  [(let* () b1 b2 ...)
   (let () b1 b2 ...)]
  [(let* ([x e] more ...) b1 b2 ...)
   (let ([x e]) (let* (more ...) b1 b2 ...))])
\end{verbatim}

The first pattern/template pair matches any \texttt{let*} expression with no identifier/value pairs and maps it into the equivalent \texttt{begin} expression. This is the base case. The second pattern/template pair matches any \texttt{let*} expression with one or more identifier/value pairs and transforms it into a \texttt{let} expression binding the first pair whose body is a \texttt{let*} expression binding the remaining pairs. This is the recursion step, which will eventually lead us to the base case because we remove one identifier/value pair at each step. Notice that the second pattern uses the pattern variable \texttt{more} for the second and later identifier/value pairs; this makes the pattern and template less cluttered and makes it clear that only the first identifier/value pair is dealt with explicitly.

The definition for \texttt{and} requires three clauses. The first clause is necessary to recognize \texttt{(and)}, and the second two define all other \texttt{and} forms recursively.

\begin{verbatim}
(extend-syntax (and)
  [(and) #t]
  [(and x) x]
  [(and x y ...) (if x (and y ...) #f)]])
\end{verbatim}

The definition for \texttt{cond} requires four clauses. As with \texttt{let*}, \texttt{cond} must be described re-
16.2. Extend-Syntax Macros

cursively, partly because it produces nested if expressions, and partly because one ellipsis prototype would not be sufficient to describe all possible cond clauses. The definition of cond also requires that we specify else as a keyword, in addition to cond. Here is the definition:

```
(defun extend-syntax (cond else)
  ((cond) 'f)
  ((cond (else e1 e2 ...))
   (begin e1 e2 ...))
  ((cond (test) more ...)
   (or test (cond more ...)))
  ((cond (test e1 e2 ...) more ...)
   (if test
    (begin e1 e2 ...)
    (cond more ...)))
)
```

Two of the clauses are base cases and two are recursion steps. The first base case is an empty cond. The value of cond in this case is unspecified, so the choice of #f is somewhat arbitrary. The second base case is a cond containing only an else clause; this is transformed to the equivalent begin expression. The two recursion steps differ in the number of expressions in the cond clause. The value of cond when the first true clause contains only the test expression is the value of the test. This is similar to what or does, so we expand the cond clause into an or expression. On the other hand, when there are expressions following the test expression, the value of the last expression is returned, so we use if and begin.

To be absolutely correct about the syntax of let, we actually must require that the bound identifiers in the input are symbols. If we typed something like (let ([3 x]) x) we would not get an error from let because it does not check to verify that the objects in the identifier positions are symbols. Instead, lambda may complain, or perhaps the system evaluator long after expansion is complete. This is where fenders are useful.

```
(defun extend-syntax (let)
  ((let ([x e] ...) b1 b2 ...)
   (andmap symbol? '(x ...))
   ((lambda (x ... b1 b2 ... e ...)))
)
```

The andmap of symbol? over '(x ...) assures that each bound identifier is a symbol. A fender is simply a Scheme expression. Within that expression, any quoted object is first expanded by the same rules as the template part of the clause. In this case, '(x ...) is expanded to the list of identifiers from the identifier/value pairs.

extend-syntax typically handles everything you need it for, but some syntactic extension definitions require the ability to include the result of evaluating an arbitrary Scheme expression. This ability is provided by with.

```
(with ((pat expr) ...) template)
```

**syntax**

**returns:** processed template

with is valid only within an template inside of extend-syntax. with patterns are the same
as `extend-syntax` patterns, `with` expressions are the same as `extend-syntax` fenders, and `with` templates are the same as `extend-syntax` templates.

`with` can be used to introduce new pattern identifiers bound to expressions produced by arbitrary Scheme expressions within `extend-syntax` templates. That is, `with` allows an escape from the declarative style of `extend-syntax` into the procedural style of full Scheme.

One common use of `with` is the introduction of a temporary identifier or list of temporary identifiers into a template. `with` is also used to perform complex transformations that might be clumsy or inefficient if performed within the `extend-syntax` framework.

For example, `or` requires the use of a temporary identifier. We could define `or` as follows.

```scheme
(extend-syntax (or)
  [(or) #f]
  [(or x) x]
  [(or x y ...) (let ([temp x])
      (if temp temp (or y ...)))]
)
```

This would work until we placed an `or` expression within the scope of an occurrence of `temp`, in which case strange things could happen, since `extend-syntax` does not respect lexical scoping. (This is one of the reasons that `define-syntax` is preferable to `extend-syntax`.)

```scheme
(let ([temp #t])
  (or #f temp)) ⇒ #f
```

One solution is to use `gensym` and `with` to create a temporary identifier, as follows.

```scheme
(extend-syntax (or)
  [(or) #f]
  [(or x) x]
  [(or x y ...) (with ([temp (gensym)])
      (let ([temp x])
        (if temp temp (or y ...))))]
)
```

Also, `with` can be used to combine elements of the input pattern in ways not possible directly with `extend-syntax`, such as the following `folding-plus` example.

```scheme
(extend-syntax (folding-plus)
  [(folding-plus x y) (and (number? 'x) (number? 'y))
    (with ([val (+ 'x 'y)])
      val)]
  [(folding-plus x y) (+ x y)])
```

`folding-plus` collapses into the value of `(+ x y)` if both `x` and `y` are numeric constants. Otherwise, `folding-plus` is transformed into `(+ x y)` for later evaluation. The fender checks that the operands are numbers at expansion time, and the `with` performs the evaluation. As with fenders, expansion is performed only within a quoted expressions, since `quote` sets the data apart from the remainder of the Scheme expression.
The example below binds a list of pattern variables to a list of temporary symbols, taking advantage of the fact that `with` allows us to bind patterns to expressions. This list of temporaries helps us to implement the `sigma` syntactic extension. `sigma` is similar to `lambda`, except it assigns the identifiers in the identifier list instead of creating new bindings. It may be used to perform a series of assignments in parallel.

```
(extend-syntax (sigma)
  [(sigma (x ...) e1 e2 ...)
   (with ([[(t ...) (map (lambda (x) (gensym)) '(x ...))]])
     (lambda (t ...)
       (set! x t) ...
       e1 e2 ...)))]

(let ([x 'a] [y 'b])
  ((sigma (x y) (list x y)) y x)) ⇒ (b a)
```

The final example below uses `extend-syntax` to implement `define-structure`, following a similar example using `syntax-case` in Section 8.4 of *The Scheme Programming Language, 4th Edition*.

The definition of `define-structure` makes use of two pattern/template clauses. Two clauses are needed to handle the optionality of the second subexpression. The first clause matches the form without the second subexpression and merely converts it into the equivalent form with the second subexpression present, but empty.

The definition also makes heavy use of `with` to evaluate Scheme expressions at expansion time. The first four `with` clauses are used to manufacture the identifiers that name the automatically defined procedures. (The procedure `format` is particularly useful here, but it could be replaced with `string-append`, using `symbol->string` as needed.) The first two clauses yield single identifiers (for the constructor and predicate), while the next two yield lists of identifiers (for the field access and assignment procedures). The fifth `with` clause (the final clause in the outer `with`) is used to count the total length vector needed for each instance of the structure, which must include room for the name and all of the fields. The final `with` clause (the only clause in the inner `with`) is used to create a list of vector indexes, one for each field (starting at 1, since the structure name occupies position 0).

```
(extend-syntax (define-structure)
  [(define-structure (name id1 ...))
   (define-structure (name id1 ...) ()])
  [(define-structure (name id1 ...) ([id2 val] ...))
   (with ([constructor
           (string->symbol (format "make-~a" 'name))])
     [predicate
      (string->symbol (format "-a?" 'name))]
     [(access ...)
      (map (lambda (x)
        (string->symbol
         (format "~-a-~-a" 'name x)))
             '(id1 ... id2 ...)])
     [(assign ...)]
  ```
16.3. Structures

This section describes a mechanism, similar to the record-defining mechanisms of Section 7.17, that permits the creation of data structures with fixed sets of named fields. Unlike record types, structure types are not unique types, but are instead implemented as vectors. Specifically, a structure is implemented as a vector whose length is one more than the number of fields and whose first element contains the symbolic name of the structure.

The representation of structures as vectors simplifies reading and printing of structures somewhat as well as extension of the structure definition facility. It does, however, have some drawbacks. One is that structures may be treated as ordinary vectors by mistake in situations where doing so is inappropriate. When dealing with both structures and vectors in a program, care must be taken to look for the more specific structure type before checking for the more generic vector type, e.g., in a series of cond clauses. A similar drawback is that structure instances are easily “forged,” either intentionally or by accident. It is also impossible to control how structures are printed and read.

Structures are created via define-structure. Each structure definition defines a constructor procedure, a type predicate, an access procedure for each of its fields, and an assignment
16.3. Structures

procedure for each of its fields. define-structure allows the programmer to control which fields are arguments to the generated constructor procedure and which fields are explicitly initialized by the constructor procedure.

define-structure is simple yet powerful enough for most applications, and it is easily extended to handle many applications for which it is not sufficient. The definition of define-structure given at the end of this section can serve as a starting point for more complicated variants.

(define-structure (name id1 ...) ((id2 expr) ...)) syntax

returns: unspecified

libraries: (chezscheme)

A define-structure form is a definition and may appear anywhere and only where other definitions may appear.

define-structure defines a new data structure, name, and creates a set of procedures for creating and manipulating instances of the structure. The identifiers id1 ... and id2 ... name the fields of the data structure.

The following procedures are defined by define-structure:

- a constructor procedure whose name is make-name,
- a type predicate whose name is name?,
- an access procedure whose name is name-field for each field name id1 ... and id2 ..., and
- an assignment procedure whose name is set-name-field! for each field name id1 ... and id2 ....

The fields named by the identifiers id1 ... are initialized by the arguments to the constructor procedure. The fields named by the identifiers id2 ... are initialized explicitly to the values of the expressions expr .... Each expression is evaluated within the scope of the identifiers id1 ... (bound to the corresponding field values) and any of the identifiers id2 ... (bound to the corresponding field values) appearing before it (as if within a let*).

To clarify, the constructor behaves as if defined as

(define make-name
  (lambda (id1 ...)
    (let* ([id2 expr] ...)
      body)))

where body builds the structure from the values of the identifiers id1 ... and id2 ....

If no fields other than those initialized by the arguments to the constructor procedure are needed, the second subexpression, ((id2 expr) ...), may be omitted.

The following simple example demonstrates how pairs might be defined in Scheme if they did not already exist. Both fields are initialized by the arguments to the constructor procedure.
(define-structure (pare car cdr))
(define p (make-pare 'a 'b))

(pare? p) ⇒ #t
(pair? p) ⇒ #f
(pare? '(a . b)) ⇒ #f

(pare-car p) ⇒ a
(pare-cdr p) ⇒ b

(set-pare-cdr! p (make-pare 'b 'c))

(pare-car (pare-cdr p)) ⇒ b
(pare-cdr (pare-cdr p)) ⇒ c

The following example defines a handy string data structure, called a *stretch-string*, that grows as needed. This example uses a field explicitly initialized to a value that depends on the value of the constructor argument fields.

(define-structure (stretch-string length fill)
  ([string (make-string length fill)]))

(define stretch-string-ref
  (lambda (s i)
    (let ([n (stretch-string-length s)])
      (when (>= i n) (stretch-stretch-string! s (+ i 1) n))
      (string-ref (stretch-string-string s) i))))

(define stretch-string-set!
  (lambda (s i c)
    (let ([n (stretch-string-length s)])
      (when (>= i n) (stretch-stretch-string! s (+ i 1) n))
      (string-set! (stretch-string-string s) i c))))

(define stretch-string-fill!
  (lambda (s c)
    (string-fill! (stretch-string-string s) c)
    (set-stretch-string-fill! s c)))

(define stretch-stretch-string!
  (lambda (s i n)
    (set-stretch-string-length! s i)
    (let ([str (stretch-string-string s)]
          [fill (stretch-string-fill s)])
      (let ([xtra (make-string (- i n) fill)])
        (set-stretch-string-string! s
          (string-append str xtra))))))

As often happens, most of the procedures defined automatically are used only to define more specialized procedures, in this case the procedures *stretch-string-ref* and *stretch-string-set!*. *stretch-string-length* and *stretch-string-string* are the only automatically defined procedures that are likely to be called directly in code that uses
stretch strings.

(define ss (make-stretch-string 2 #\X))

(stretch-string-string ss) ⇒ "XX"
(stretch-string-ref ss 3) ⇒ #\X
(stretch-string-length ss) ⇒ 4
(stretch-string-string ss) ⇒ "XXXX"

(stretch-string-fill! ss #\@
(stretch-string-string ss) ⇒ "@@@@"
(stretch-string-ref ss 5) ⇒ #\@
(stretch-string-string ss) ⇒ "@@@@@@"

(stretch-string-set! ss 7 #\=)
(stretch-string-length ss) ⇒ 8
(stretch-string-string ss) ⇒ "@@@@@@="

Section 8.4 of *The Scheme Programming Language, 4th Edition* defines a simplified variant of `define-structure` as an example of the use of `syntax-case`. The definition given below implements the complete version.

`define-structure` expands into a series of definitions for names generated from the structure name and field names. The generated identifiers are created with `datum->syntax` to make the identifiers visible where the `define-structure` form appears. Since a `define-structure` form expands into a `begin` containing definitions, it is itself a definition and can be used wherever definitions are valid.

(define-syntax define-structure
  (lambda (x)
    (define gen-id
      (lambda (template-id . args)
        (datum->syntax template-id
          (string->symbol
            (apply string-append
              (map (lambda (x)
                (if (string? x)
                  x
                  (symbol->string
                    (syntax->datum x)))))
              args))))))
    (syntax-case x ()
      ((_ (name field1 ...))
        (andmap identifier? #'(name field1 ...))
        #'(define-structure (name field1 ...) ()
            ((_ (name field1 ...) ((field2 init) ...))
                (andmap identifier? #'(name field1 ... field2 ...) (with-syntax
                  ((constructor (gen-id #'name "make-" #'name))
                          (predicate (gen-id #'name #'name ")")
                          ((access ...))
        )
        )
    ))

}}}
16. Compatibility Features

```scheme
(map (lambda (x) (gen-id x '#name "-" x))
   #'(field1 ... field2 ...)))
((assign ...)
 (map (lambda (x) (gen-id x "set-" '#name "-" x "!"))
   #'(field1 ... field2 ...)))
(structure-length
 (+ (length #'(field1 ... field2 ...)) 1))
((index ...)
 (let f ([i 1] [ids #'(field1 ... field2 ...)])
   (if (null? ids)
     ()
     (cons i (f (+ i 1) (cdr ids))))))
#'begin
 (define constructor
   (lambda (field1 ...)
     (let* ([field2 init] ...)
       (vector 'name field1 ... field2 ...))))
(define predicate
 (lambda (x)
   (and (vector? x)
    (#3%fx= (vector-length x) structure-length)
    (eq? (vector-ref x 0) 'name))))
(define access (lambda (x) (vector-ref x index)))
...
(define assign
 (lambda (x update) (vector-set! x index update)))
)...)
```

16.4. Compatibility File

Current versions of Chez Scheme are distributed with a compatibility file containing definitions of various syntactic forms and procedures supported by earlier versions of Chez Scheme for which support has since been dropped. This file, `compat.ss`, is typically installed in the library subdirectory of the Chez Scheme installation directory.

In some cases, the forms and procedures found in `compat.ss` have been dropped because they were infrequently used and easily written directly in Scheme. In other cases, the forms and procedures have been rendered obsolete by improvements in the system. In such cases, new code should be written to use the newer features, and older code should be rewritten if possible to use the newer features as well.
References


## Summary of Forms

The table that follows summarizes the syntactic forms and procedures described in this book along with standard Scheme syntactic forms and procedures. It shows each item’s category and the page number where it is defined. Page numbers prefixed by “t” refer to *The Scheme Programming Language, 4th Edition* (TSPL4).

<table>
<thead>
<tr>
<th>Form</th>
<th>Category</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>obj</code></td>
<td>syntax</td>
<td>141</td>
</tr>
<tr>
<td><code>obj</code></td>
<td>syntax</td>
<td>142</td>
</tr>
<tr>
<td>,obj</td>
<td>syntax</td>
<td>142</td>
</tr>
<tr>
<td>,@obj</td>
<td>syntax</td>
<td>142</td>
</tr>
<tr>
<td>=&gt;</td>
<td>syntax</td>
<td>112</td>
</tr>
<tr>
<td>-</td>
<td>syntax</td>
<td>297</td>
</tr>
<tr>
<td>...</td>
<td>syntax</td>
<td>297</td>
</tr>
<tr>
<td>#`template</td>
<td>syntax</td>
<td>300</td>
</tr>
<tr>
<td>#`template</td>
<td>syntax</td>
<td>305</td>
</tr>
<tr>
<td>#template</td>
<td>syntax</td>
<td>305</td>
</tr>
<tr>
<td>#,template</td>
<td>syntax</td>
<td>305</td>
</tr>
<tr>
<td>#%variable</td>
<td>syntax</td>
<td>390</td>
</tr>
<tr>
<td>#%variable</td>
<td>syntax</td>
<td>390</td>
</tr>
<tr>
<td>(#%variable)</td>
<td>syntax</td>
<td>390</td>
</tr>
<tr>
<td>(#%variable)</td>
<td>syntax</td>
<td>390</td>
</tr>
<tr>
<td>($%variable)</td>
<td>module</td>
<td>339</td>
</tr>
<tr>
<td>&amp;assertion</td>
<td>syntax</td>
<td>366</td>
</tr>
<tr>
<td>&amp;condition</td>
<td>syntax</td>
<td>362</td>
</tr>
<tr>
<td>&amp;continuation</td>
<td>syntax</td>
<td>355</td>
</tr>
<tr>
<td>&amp;error</td>
<td>syntax</td>
<td>367</td>
</tr>
<tr>
<td>&amp;format</td>
<td>syntax</td>
<td>354</td>
</tr>
<tr>
<td>&amp;i/o</td>
<td>syntax</td>
<td>371</td>
</tr>
<tr>
<td>&amp;i/o-decoding</td>
<td>syntax</td>
<td>375</td>
</tr>
<tr>
<td>&amp;i/o-encoding</td>
<td>syntax</td>
<td>376</td>
</tr>
<tr>
<td>&amp;i/o-file-already-exists</td>
<td>syntax</td>
<td>374</td>
</tr>
<tr>
<td>&amp;i/o-file-does-not-exist</td>
<td>syntax</td>
<td>374</td>
</tr>
<tr>
<td>&amp;i/o-file-is-read-only</td>
<td>syntax</td>
<td>374</td>
</tr>
<tr>
<td>&amp;i/o-file-protection</td>
<td>syntax</td>
<td>373</td>
</tr>
<tr>
<td>&amp;i/o-filename</td>
<td>syntax</td>
<td>373</td>
</tr>
<tr>
<td>&amp;i/o-invalid-position</td>
<td>syntax</td>
<td>372</td>
</tr>
</tbody>
</table>
### Summary of Forms

<table>
<thead>
<tr>
<th>Form</th>
<th>Syntax</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;i/o-port</td>
<td>375</td>
<td></td>
</tr>
<tr>
<td>&amp;i/o-read</td>
<td>372</td>
<td></td>
</tr>
<tr>
<td>&amp;i/o-write</td>
<td>372</td>
<td></td>
</tr>
<tr>
<td>&amp;implementation-restriction</td>
<td>369</td>
<td></td>
</tr>
<tr>
<td>&amp;irritants</td>
<td>368</td>
<td></td>
</tr>
<tr>
<td>&amp;lexical</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>&amp;message</td>
<td>368</td>
<td></td>
</tr>
<tr>
<td>&amp;no-infinities</td>
<td>376</td>
<td></td>
</tr>
<tr>
<td>&amp;no-nans</td>
<td>377</td>
<td></td>
</tr>
<tr>
<td>&amp;non-continuable</td>
<td>369</td>
<td></td>
</tr>
<tr>
<td>&amp;serious</td>
<td>366</td>
<td></td>
</tr>
<tr>
<td>&amp;source</td>
<td>374</td>
<td></td>
</tr>
<tr>
<td>&amp;syntax</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>&amp;undefined</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td>&amp;violation</td>
<td>366</td>
<td></td>
</tr>
<tr>
<td>&amp;warning</td>
<td>367</td>
<td></td>
</tr>
<tr>
<td>&amp;who</td>
<td>369</td>
<td></td>
</tr>
<tr>
<td>(* num ...)</td>
<td></td>
<td>172</td>
</tr>
<tr>
<td>(+ num ...)</td>
<td></td>
<td>171</td>
</tr>
<tr>
<td>(- num)</td>
<td></td>
<td>172</td>
</tr>
<tr>
<td>(- num1 num2 num3 ...)</td>
<td></td>
<td>172</td>
</tr>
<tr>
<td>(-i+ num)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(/ num)</td>
<td></td>
<td>172</td>
</tr>
<tr>
<td>(/ num1 num2 num3 ...)</td>
<td></td>
<td>172</td>
</tr>
<tr>
<td>(1+ num)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(1- num)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(&lt; real1 real2 real3 ...)</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>(&lt; real1 real2 real3 ...)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(&lt;= real1 real2 real3 ...)</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>(&lt;= real1 real2 real3 ...)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(= num1 num2 num3 ...)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(= num1 num2 num3 ...)</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>(&gt; real1 real2 real3 ...)</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>(&gt; real1 real2 real3 ...)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(&gt;= real1 real2 real3 ...)</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>(&gt;= real1 real2 real3 ...)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>(abort)</td>
<td></td>
<td>410</td>
</tr>
<tr>
<td>(abort obj)</td>
<td></td>
<td>410</td>
</tr>
<tr>
<td>abort-handler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(abs real)</td>
<td></td>
<td>178</td>
</tr>
<tr>
<td>(acos num)</td>
<td></td>
<td>185</td>
</tr>
<tr>
<td>(acosh num)</td>
<td></td>
<td>238</td>
</tr>
<tr>
<td>(add-duration time time_d)</td>
<td></td>
<td>416</td>
</tr>
<tr>
<td>(add-duration! time time_d)</td>
<td></td>
<td>416</td>
</tr>
<tr>
<td>add-prefix</td>
<td></td>
<td>338</td>
</tr>
<tr>
<td>(add1 num)</td>
<td></td>
<td>235</td>
</tr>
<tr>
<td>alias</td>
<td></td>
<td>338</td>
</tr>
<tr>
<td>(alias id1 id2)</td>
<td></td>
<td>342</td>
</tr>
<tr>
<td>(and expr ...)</td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>(andmap procedure list1 list2 ...)</td>
<td></td>
<td>129</td>
</tr>
<tr>
<td>Function</td>
<td>Type</td>
<td>Line</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>------------</td>
<td>------</td>
</tr>
<tr>
<td>(angle num)</td>
<td>procedure</td>
<td>183</td>
</tr>
<tr>
<td>(annotation-expression annotation)</td>
<td>procedure</td>
<td>345</td>
</tr>
<tr>
<td>(annotation-option-set annotation)</td>
<td>procedure</td>
<td>346</td>
</tr>
<tr>
<td>(annotation-options symbol ...)</td>
<td>syntax</td>
<td>348</td>
</tr>
<tr>
<td>(annotation-source annotation)</td>
<td>procedure</td>
<td>346</td>
</tr>
<tr>
<td>(annotation-stripped annotation)</td>
<td>procedure</td>
<td>346</td>
</tr>
<tr>
<td>(annotation? obj)</td>
<td>procedure</td>
<td>345</td>
</tr>
<tr>
<td>(append)</td>
<td>procedure</td>
<td>160</td>
</tr>
<tr>
<td>(append list ... obj)</td>
<td>procedure</td>
<td>160</td>
</tr>
<tr>
<td>(append! list ...)</td>
<td>procedure</td>
<td>147</td>
</tr>
<tr>
<td>(apply procedure obj ... list)</td>
<td>procedure</td>
<td>107</td>
</tr>
<tr>
<td>(apropos s)</td>
<td>procedure</td>
<td>364</td>
</tr>
<tr>
<td>(apropos s env)</td>
<td>procedure</td>
<td>364</td>
</tr>
<tr>
<td>(apropos-list s)</td>
<td>procedure</td>
<td>363</td>
</tr>
<tr>
<td>(apropos-list s env)</td>
<td>procedure</td>
<td>363</td>
</tr>
<tr>
<td>(ash int count)</td>
<td>procedure</td>
<td>228</td>
</tr>
<tr>
<td>(asin num)</td>
<td>procedure</td>
<td>185</td>
</tr>
<tr>
<td>(asinh num)</td>
<td>procedure</td>
<td>238</td>
</tr>
<tr>
<td>(assert expression)</td>
<td>syntax</td>
<td>359</td>
</tr>
<tr>
<td>(assert-unreachable)</td>
<td>procedure</td>
<td>357</td>
</tr>
<tr>
<td>(assertion-violation who msg irritant ...)</td>
<td>procedure</td>
<td>358</td>
</tr>
<tr>
<td>(assertion-violation? obj)</td>
<td>procedure</td>
<td>366</td>
</tr>
<tr>
<td>(assertion-violationf who msg irritant ...)</td>
<td>procedure</td>
<td>354</td>
</tr>
<tr>
<td>(assoc obj alist)</td>
<td>procedure</td>
<td>165</td>
</tr>
<tr>
<td>(assp procedure alist)</td>
<td>procedure</td>
<td>166</td>
</tr>
<tr>
<td>(assq obj alist)</td>
<td>procedure</td>
<td>165</td>
</tr>
<tr>
<td>(assv obj alist)</td>
<td>procedure</td>
<td>165</td>
</tr>
<tr>
<td>(atan num)</td>
<td>procedure</td>
<td>185</td>
</tr>
<tr>
<td>(atanh num)</td>
<td>procedure</td>
<td>238</td>
</tr>
<tr>
<td>(atom? obj)</td>
<td>procedure</td>
<td>143</td>
</tr>
<tr>
<td>base-exception-handler</td>
<td>thread param</td>
<td>356</td>
</tr>
<tr>
<td>(begin expr1 expr2 ...)</td>
<td>syntax</td>
<td>108</td>
</tr>
<tr>
<td>(bignum? obj)</td>
<td>procedure</td>
<td>214</td>
</tr>
<tr>
<td>(binary-port-input-buffer binary-input-port)</td>
<td>procedure</td>
<td>246</td>
</tr>
<tr>
<td>(binary-port-input-count binary-input-port)</td>
<td>procedure</td>
<td>247</td>
</tr>
<tr>
<td>(binary-port-input-index binary-input-port)</td>
<td>procedure</td>
<td>246</td>
</tr>
<tr>
<td>(binary-port-input-size binary-input-port)</td>
<td>procedure</td>
<td>246</td>
</tr>
<tr>
<td>(binary-port-output-buffer output-port)</td>
<td>procedure</td>
<td>247</td>
</tr>
<tr>
<td>(binary-port-output-count binary-output-port)</td>
<td>procedure</td>
<td>248</td>
</tr>
<tr>
<td>(binary-port-output-index output-port)</td>
<td>procedure</td>
<td>247</td>
</tr>
<tr>
<td>(binary-port-output-size output-port)</td>
<td>procedure</td>
<td>247</td>
</tr>
<tr>
<td>(binary-port? obj)</td>
<td>procedure</td>
<td>270</td>
</tr>
<tr>
<td>(bitwise-and exint ...)</td>
<td>procedure</td>
<td>186</td>
</tr>
<tr>
<td>(bitwise-arithmetic-shift exint1 exint2)</td>
<td>procedure</td>
<td>190</td>
</tr>
<tr>
<td>(bitwise-arithmetic-shift-left exint1 exint2)</td>
<td>procedure</td>
<td>189</td>
</tr>
<tr>
<td>(bitwise-arithmetic-shift-right exint1 exint2)</td>
<td>procedure</td>
<td>189</td>
</tr>
<tr>
<td>(bitwise-bit-count exint)</td>
<td>procedure</td>
<td>187</td>
</tr>
<tr>
<td>(bitwise-bit-field exint1 exint2 exint3)</td>
<td>procedure</td>
<td>189</td>
</tr>
<tr>
<td>(bitwise-bit-set? exint1 exint2)</td>
<td>procedure</td>
<td>188</td>
</tr>
<tr>
<td>Procedure</td>
<td>Line</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>(bitwise-copy-bit exint1 exint2 exint3)</td>
<td>188</td>
<td></td>
</tr>
<tr>
<td>(bitwise-copy-bit-field exint1 exint2 exint3 exint4)</td>
<td>189</td>
<td></td>
</tr>
<tr>
<td>(bitwise-first-bit-set exint)</td>
<td>181</td>
<td></td>
</tr>
<tr>
<td>(bitwise-if exint1 exint2 exint3)</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>(bitwise-ior exint ...)</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>(bitwise-length exint)</td>
<td>187</td>
<td></td>
</tr>
<tr>
<td>(bitwise-not exint)</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>(bitwise-reverse-bit-field exint1 exint2 exint3)</td>
<td>191</td>
<td></td>
</tr>
<tr>
<td>(bitwise-rotate-bit-field exint1 exint2 exint3 exint4)</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>(bitwise-xor exint ...)</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>(block-read textual-input-port string)</td>
<td>262</td>
<td></td>
</tr>
<tr>
<td>(block-read textual-input-port string count)</td>
<td>262</td>
<td></td>
</tr>
<tr>
<td>(block-write textual-output-port string)</td>
<td>269</td>
<td></td>
</tr>
<tr>
<td>(block-write textual-output-port string count)</td>
<td>269</td>
<td></td>
</tr>
<tr>
<td>(boolean=? boolean1 boolean2)</td>
<td>243</td>
<td></td>
</tr>
<tr>
<td>(boolean? obj)</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>(bound-identifier=? identifier1 identifier2)</td>
<td>302</td>
<td></td>
</tr>
<tr>
<td>(box obj)</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>(box-cas! box old-obj new-obj)</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>(box-immobile obj)</td>
<td>452</td>
<td></td>
</tr>
<tr>
<td>(box-immutable obj)</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>(box? obj)</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>(break who msg irritant ...)</td>
<td>358</td>
<td></td>
</tr>
<tr>
<td>(break who)</td>
<td>358</td>
<td></td>
</tr>
<tr>
<td>(break)</td>
<td>358</td>
<td></td>
</tr>
<tr>
<td>(break)</td>
<td>358</td>
<td></td>
</tr>
<tr>
<td>(break-handler)</td>
<td>358</td>
<td></td>
</tr>
<tr>
<td>(buffer-mode symbol)</td>
<td>261</td>
<td></td>
</tr>
<tr>
<td>(buffer-mode? obj)</td>
<td>262</td>
<td></td>
</tr>
<tr>
<td>(bwp-object? obj)</td>
<td>445</td>
<td></td>
</tr>
<tr>
<td>(bytes-allocated)</td>
<td>422</td>
<td></td>
</tr>
<tr>
<td>(bytes-allocated g)</td>
<td>422</td>
<td></td>
</tr>
<tr>
<td>(bytes-deallocated)</td>
<td>422</td>
<td></td>
</tr>
<tr>
<td>(bytes-finalized)</td>
<td>422</td>
<td></td>
</tr>
<tr>
<td>(bytevector fill ...)</td>
<td>161</td>
<td></td>
</tr>
<tr>
<td>(bytevector-&gt;immutable-bytevector bytevector)</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>(bytevector-&gt;s8-list bytevector)</td>
<td>161</td>
<td></td>
</tr>
<tr>
<td>(bytevector-&gt;sint-list bytevector eness size)</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>(bytevector-&gt;string bytevector transcoder)</td>
<td>286</td>
<td></td>
</tr>
<tr>
<td>(bytevector-&gt;u8-list bytevector)</td>
<td>232</td>
<td></td>
</tr>
<tr>
<td>(bytevector-&gt;uint-list bytevector eness size)</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>(bytevector-compress bytevector)</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>(bytevector-copy bytevector)</td>
<td>229</td>
<td></td>
</tr>
<tr>
<td>(bytevector-copy! src src-start dst dst-start n)</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>(bytevector-fill! bytevector fill)</td>
<td>229</td>
<td></td>
</tr>
<tr>
<td>(bytevector-ieee-double-native-ref bytevector n)</td>
<td>239</td>
<td></td>
</tr>
<tr>
<td>(bytevector-ieee-double-native-set! bytevector n x)</td>
<td>239</td>
<td></td>
</tr>
<tr>
<td>(bytevector-ieee-double-ref bytevector n eness)</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>(bytevector-ieee-double-set! bytevector n x eness)</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>(bytevector-ieee-single-native-ref bytevector n)</td>
<td>239</td>
<td></td>
</tr>
<tr>
<td>(bytevector-ieee-single-native-set! bytevector n x)</td>
<td>239</td>
<td></td>
</tr>
</tbody>
</table>
(bytevector-ieee-single-ref bytevector n eness) procedure 240
(byevector-ieee-single-set! bytevector n x eness) procedure 240
(bytevector-length bytevector) procedure 229
(bytevector-reference-ref bytevector n) procedure 92
(bytevector-reference-ref bytevector n) procedure 91
(bytevector-reference-set! bytevector n obj) procedure 91
(bytevector-s16-native-ref bytevector n s16) procedure 232
(bytevector-s16-native-set! bytevector n s16 eness) procedure 233
(bytevector-s16-ref bytevector n eness) procedure 233
(bytevector-s16-set! bytevector n s16 eness) procedure 163
<bytevector-s24-native-ref bytevector n> procedure 232
<bytevector-s24-native-set! bytevector n s16 eness) procedure 233
<bytevector-s24-ref bytevector n eness) procedure 163
<bytevector-s24-set! bytevector n s16 eness) procedure 163
(bytevector-s32-native-ref bytevector n) procedure 232
<bytevector-s32-native-set! bytevector n s32) procedure 233
<bytevector-s32-ref bytevector n eness) procedure 235
<bytevector-s32-set! bytevector n s32 eness) procedure 236
<bytevector-s40-ref bytevector n eness) procedure 163
<bytevector-s40-set! bytevector n s40 eness) procedure 163
<bytevector-s48-native-ref bytevector n) procedure 163
<bytevector-s48-native-set! bytevector n s48 eness) procedure 163
<bytevector-s48-ref bytevector n eness) procedure 163
<bytevector-s48-set! bytevector n s48 eness) procedure 163
<bytevector-s56-native-ref bytevector n) procedure 232
<bytevector-s56-native-set! bytevector n s64) procedure 233
<bytevector-s56-ref bytevector n eness) procedure 163
<bytevector-s56-set! bytevector n s56 eness) procedure 163
<bytevector-s64-native-ref bytevector n) procedure 232
<bytevector-s64-native-set! bytevector n s64) procedure 233
<bytevector-s64-ref bytevector n eness) procedure 235
<bytevector-s64-set! bytevector n s64 eness) procedure 236
<bytevector-u16-native-ref bytevector n) procedure 162
<bytevector-u16-native-set! bytevector n u16) procedure 232
<bytevector-u16-ref bytevector n eness) procedure 233
<bytevector-u16-set! bytevector n u16 eness) procedure 235
<bytevector-u24-native-ref bytevector n) procedure 163
<bytevector-u24-native-set! bytevector n u24) procedure 232
<bytevector-u24-ref bytevector n eness) procedure 163
<bytevector-u24-set! bytevector n u24 eness) procedure 233
<bytevector-u32-native-ref bytevector n) procedure 232
<bytevector-u32-native-set! bytevector n u32) procedure 233
<bytevector-u32-ref bytevector n eness) procedure 235
<bytevector-u32-set! bytevector n u32 eness) procedure 236
<bytevector-u40-ref bytevector n eness) procedure 163
<bytevector-u40-set! bytevector n u40 eness) procedure 163
<bytevector-u48-native-ref bytevector n) procedure 163
<bytevector-u48-native-set! bytevector n u64) procedure 163
<bytevector-u48-ref bytevector n eness) procedure 163
<bytevector-u48-set! bytevector n u48 eness) procedure 163
<bytevector-u56-native-ref bytevector n) procedure 163
<bytevector-u56-native-set! bytevector n u56) procedure 163
<bytevector-u56-ref bytevector n eness) procedure 163
<bytevector-u56-set! bytevector n u56 eness) procedure 163
<bytevector-u64-native-ref bytevector n) procedure 232
<bytevector-u64-native-set! bytevector n u64) procedure 233
<bytevector-u64-ref bytevector n eness) procedure 235
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>(bytevector-u64-set! bytevector n u64 eness)</td>
<td>236</td>
</tr>
<tr>
<td>(bytevector-u8-ref bytevector n)</td>
<td>230</td>
</tr>
<tr>
<td>(bytevector-u8-set! bytevector n u8)</td>
<td>231</td>
</tr>
<tr>
<td>(bytevector-uint-ref bytevector n eness size)</td>
<td>237</td>
</tr>
<tr>
<td>(bytevector-uint-set! bytevector n uint eness size)</td>
<td>238</td>
</tr>
<tr>
<td>(bytevector-uncompress bytevector)</td>
<td>164</td>
</tr>
<tr>
<td>(bytevector=? bytevector1 bytevector2)</td>
<td>229</td>
</tr>
<tr>
<td>(bytevector? obj)</td>
<td>155</td>
</tr>
<tr>
<td>(caaaar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caadrr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caaar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cadar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caaddr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caadr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cadaar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cadadr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cadar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caddar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(caddr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cadddr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(call-in-continuation continuation procedure)</td>
<td>135</td>
</tr>
<tr>
<td>(call-with-bytevector-output-port procedure)</td>
<td>266</td>
</tr>
<tr>
<td>(call-with-bytevector-output-port procedure ?transcoder)</td>
<td>266</td>
</tr>
<tr>
<td>(call-with-current-continuation procedure)</td>
<td>123</td>
</tr>
<tr>
<td>(call-with-immediate-continuation-mark key proc)</td>
<td>135</td>
</tr>
<tr>
<td>(call-with-immediate-continuation-mark key none-val proc)</td>
<td>135</td>
</tr>
<tr>
<td>(call-with-input-file path procedure)</td>
<td>258</td>
</tr>
<tr>
<td>(call-with-input-file path procedure options)</td>
<td>258</td>
</tr>
<tr>
<td>(call-with-input-file path procedure)</td>
<td>281</td>
</tr>
<tr>
<td>(call-with-output-file path procedure)</td>
<td>266</td>
</tr>
<tr>
<td>(call-with-output-file path procedure options)</td>
<td>266</td>
</tr>
<tr>
<td>(call-with-port port procedure)</td>
<td>272</td>
</tr>
<tr>
<td>(call-with-string-output-port procedure)</td>
<td>267</td>
</tr>
<tr>
<td>(call-with-values producer consumer)</td>
<td>131</td>
</tr>
<tr>
<td>(call/cc procedure)</td>
<td>130</td>
</tr>
<tr>
<td>(call/cc procedure)</td>
<td>123</td>
</tr>
<tr>
<td>(car pair)</td>
<td>156</td>
</tr>
<tr>
<td>(case expr0 clause1 clause2 ...)</td>
<td>127</td>
</tr>
<tr>
<td>(case expr0 clause1 clause2 ...)</td>
<td>113</td>
</tr>
<tr>
<td>(case-lambda clause ...)</td>
<td>94</td>
</tr>
<tr>
<td>case-sensitive</td>
<td>thread param 279</td>
</tr>
<tr>
<td>cd</td>
<td>global param 288</td>
</tr>
<tr>
<td>(cdaaaar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cdaadr pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cdaar pair)</td>
<td>157</td>
</tr>
<tr>
<td>(cdadar pair)</td>
<td>157</td>
</tr>
</tbody>
</table>
(cdaddr pair) procedure 157
(cdadr pair) procedure 157
(cdar pair) procedure 157
(cddaar pair) procedure 157
(cddadr pair) procedure 157
(cddar pair) procedure 157
(cddddr pair) procedure 157
(cdddr pair) procedure 157
(cddr pair) procedure 157
(cdr pair) procedure 156
(ceiling real) procedure 177
(cfl* cflonum ...) procedure 223
(cfl+ cflonum ...) procedure 223
(cfl- cflonum1 cflonum2 ...) procedure 223
(cfl-conjugate cflonum) procedure 223
(cfl-imag-part cflonum) procedure 222
(cfl-magnitude-squared cflonum) procedure 224
(cfl-real-part cflonum) procedure 222
(cflonum? obj) procedure 215
(char- char1 char2) procedure 148
(char->integer char) procedure 215
(char-alphabetic? char) procedure 213
(char-ci<=? char1 char2 char3 ...) procedure 212
(char-ci=? char1 char2 char3 ...) procedure 212
(char-ci>? char1 char2 char3 ...) procedure 212
(char-ci<=? char1 char2 ...) procedure 148
(char-ci=? char1 char2 ...) procedure 148
(char-ci>? char1 char2 ...) procedure 148
(char-ci=? char1 char2 char3 ...) procedure 212
(char-ci>=? char1 char2 ...) procedure 148
(char-ci>=? char1 char2 char3 ...) procedure 212
(char-ci>? char1 char2 ...) procedure 148
(char-ci>? char1 char2 char3 ...) procedure 212
(char-ci>=? char1 char2 ...) procedure 148
(char-ci>? char1 char2 ...) procedure 148
(char-ci>=? char1 char2 char3 ...) procedure 212
(char-ci>? char1 char2 char3 ...) procedure 212
(char-case char) procedure 214
(char-downcase char) procedure 150
(char-foldcase char) procedure 215
(char-general-category char) procedure 214
(char-grapheme-break-property char) procedure 149
(char-grapheme-step char state) procedure 149
(char-lower-case? char) procedure 213
(char-name obj) procedure 278
(char-name name char) procedure 278
(char-numeric? char) procedure 213
(char-ready?) procedure 262
(char-ready? textual-input-port) procedure 262
(char-title-case? char) procedure 213
(char-titlecase char) procedure 214
(char-upcase char) procedure 214
(char-upper-case? char)                             procedure  213
(char-whitespace? char)                             procedure  213
(char<=? char1 char2 ...)                           procedure  148
(char<=? char1 char2 char3 ...)                    procedure  212
(char? char1 char2 ...)                             procedure  148
(char=? char1 char2 char3 ...)                    procedure  212
(char=? char1 char2 ...)                             procedure  148
(char>? char1 char2 ...)                             procedure  212
(char>? char1 char2 char3 ...)                    procedure  212
(char>? char1 char2 ...)                             procedure  148
(char<? char1 char2 ...)                             procedure  148
(char<? char1 char2 char3 ...)                    procedure  212
(char<? char1 char2 char3 ...)                    procedure  212
(char? obj)                                        procedure  154
(chmod path mode)                                  procedure  291
(clear-input-port)                                 procedure  252
(clear-input-port input-port)                      procedure  252
(clear-output-port)                                procedure  253
(clear-output-port output-port)                    procedure  253
(close-input-port input-port)                      procedure  285
(close-output-port output-port)                    procedure  285
(close-port port)                                  procedure  270
(collect)                                          procedure  439
(collect cg)                                       procedure  439
(collect cg max-tg)                                procedure  439
(collect cg min-tg max-tg)                          procedure  439
(collect cg min-tg max-tg objs)                    procedure  439
collect-generation-radix                           global param  440
collect-maximum-generation                         global param  441
collect-maximum-generation-threshold-factor       global param  440
collect-notify                                     global param  440
(collect-rendezvous)                               procedure  440
collect-request-handler                            global param  441
collect-trip-bytes                                 global param  440
(collections)                                      procedure  423
command-line                                      global param  412
(command-line)                                     procedure  359
command-line-arguments                             global param  412
commonization-level                                global param  395
(compile obj)                                      procedure  365
(compile obj env)                                  procedure  365
(compile-file input-filename)                      procedure  369
(compile-file input-filename output-filename)      procedure  369
compile-file-message                               thread param  399
compile-imported-libraries                         thread param  316
compile-interpret-simple                           thread param  391
(compile-library input-filename)                   procedure  374
(compile-library input-filename output-filename)   procedure  374
compile-library-handler                            thread param  372
compile-omit-concatenate-support                   thread param  388
(compile-port input-port output-port)              procedure  374
(compile-port input-port output-port sfd) procedure 374
(compile-port input-port output-port sfd wpo-port) procedure 374
(compile-port input-port output-port sfd wpo-port covop) procedure 374
compile-procedure-realm thread param 378
compile-profile thread param 401
(compile-program input-filename) procedure 374
(compile-program input-filename output-filename) procedure 374
compile-program-handler thread param 372
(compile-script input-filename) procedure 370
(compile-script input-filename output-filename) procedure 370
compile-time-value-value ctv) procedure 330
compile-time-value? obj) procedure 330
(compile-to-file obj-list output-file) procedure 376
(compile-to-file obj-list output-file sfd) procedure 376
(compile-to-port objs op) procedure 375
(compile-to-port objs op sfd) procedure 375
(compile-to-port objs op sfd wpoop) procedure 375
(compile-to-port objs op sfd wpoop covop) procedure 375
(compile-to-port objs op sfd wpoop covop mach) procedure 375
(compile-to-port objs op sfd wpoop covop mach hostop) procedure 375
(compile-to-port objs op sfd wpoop covop mach hostop ext) procedure 375
(compile-whole-library input-filename output-filename) procedure 374
(compile-whole-program input-filename output-filename) procedure 373
(compile-whole-program input-filename output-filename libs-visible?) procedure 373
(complex? obj) procedure 151
compress-format thread param 253
compress-level thread param 254
(compute-composition object) procedure 59
(compute-composition object generation) procedure 55
(compute-size object) procedure 54
(compute-size object generation) procedure 54
(compute-size-increments list) procedure 56
(compute-size-increments list generation) procedure 56
(concatenate-object-files out-file in-file_1 in-file_2 ...) procedure 376
(cond clause_1 clause_2 ...) syntax 111
(condition condition ...) procedure 362
(condition-accessor rtd procedure) procedure 365
(condition-broadcast cond) procedure 471
(condition-continuation condition) procedure 355
(condition-irritants condition) procedure 368
(condition-message condition) procedure 368
(condition-name condition) procedure 471
(condition-predicate rtd) procedure 365
(condition-signal cond) procedure 471
(condition-wait cond mutex) procedure 470
(condition-wait cond mutex timeout) procedure 470
(condition-who condition) procedure 369
(condition? obj) procedure 362
(conjugate num) procedure 237
Summary of Forms

(cons obj1 obj2)  
procedure 156

(cons* obj ... final-obj)  
procedure 158

console-error-port  
thread param 265

console-input-port  
global param 256

course-output-port  
global param 264

constant  
syntax 141

congstructor  
syntax 199

(continuation-condition? obj)  
procedure 355

(continuation-marks-iterator marks key-vector)  
procedure 134

(continuation-marks->iterator marks key-vector none-val)  
procedure 134

(continuation-marks->list marks key vector)  
procedure 133

(continuation-marks-first marks key)  
procedure 133

(continuation-marks-first marks key none-val)  
procedure 133

(continuation-marks? obj)  
procedure 132

(continuation-next-marks cont)  
procedure 132

(copy-environment env)  
procedure 363

(copy-environment env mutable?)  
procedure 363

(copy-environment env mutable? syms)  
procedure 363

(copy-time time)  
procedure 416

(cos num)  
procedure 185

(cosh num)  
procedure 238

(cost-center-allocation-count cost-center)  
procedure 428

(cost-center-instruction-count cost-center)  
procedure 428

(cost-center-time cost-center)  
procedure 428

(cost-center? obj)  
procedure 428
cp0-effort-limit  
thread param 393
cp0-outer-unroll-limit  
thread param 393
cp0-score-limit  
thread param 393

(cpu-time)  
procedure 421

(create-exception-state)  
procedure 357

(create-exception-state handler)  
procedure 357

(critical-section body1 body2 ...)  
syntax 360

(current-continuation-marks)  
procedure 132

(current-date)  
procedure 417

(current-date offset)  
procedure 417
current-directory  
global param 288
current-error-port  
thread param 265

(current-error-port)  
procedure 263
current-eval  
thread param 365
current-exception-state  
thread param 356
current-expand  
thread param 379
current-generate-id  
thread param 386
current-input-port  
thread param 251

(current-input-port)  
procedure 263
current-locate-source-object-source  
thread param 349
current-make-source-object  
thread param 347

(current-memory-bytes)  
procedure 422
current-output-port  
thread param 264

(current-output-port)  
procedure 263
current-time)  
procedure 414
Summary of Forms

(current-time time-type) procedure 414
current-transcoder thread param 244
custom-port-buffer-size thread param 256
(date->time-utc date) procedure 420
(date-and-time) procedure 420
(date-and-time date) procedure 420
(date-day date) procedure 418
(date-dst? date) procedure 419
(date-hour date) procedure 418
(date-minute date) procedure 418
(date-month date) procedure 418
(date-nanosecond date) procedure 418
(date-second date) procedure 418
(date-week-day date) procedure 419
(date-year date) procedure 418
(date-year-day date) procedure 419
(date-zone-name date) procedure 419
(date-zone-offset date) procedure 418
(date? obj) procedure 418
(datum template) syntax 325
(datum->syntax template-identifier obj) procedure 308
(datum->syntax-object template-identifier obj) procedure 325
(debug) procedure 41
debug-condition thread param 356
debug-level thread param 390
debug-on-exception global param 356
(decode-float x) procedure 221
default-exception-handler obj) procedure 355
default-library-search-handler who library directories extensions) procedure 317
default-prompt-and-read level) procedure 409
default-record-equal-procedure thread param 191
default-record-hash-procedure thread param 192
(define var expr) syntax 100
(define var) syntax 100
(define (var0 var1 ...) body1 body2 ...) syntax 100
(define (var0 . varr) body1 body2 ...) syntax 100
(define (var0 var1 var2 ... varr) body1 body2 ...) syntax 100
(define-condition-type name parent constructor pred field ...) syntax 364
(define-enumeration name (symbol ...) constructor) syntax 250
(define-ftype ftype-name ftype) syntax 77
(define-ftype (ftype-name ftype) ...) syntax 77
(define-property id key expr) syntax 381
(define-record name (fld1 ...) ((fld2 init) ...) (opt ...)) syntax 195
(define-record name parent (fld1 ...) ((fld2 init) ...) (opt ...)) syntax 195
(define-record-type record-name clause ...) syntax 328
(define-record-type (record-name constructor pred) clause ...) syntax 328
(define-structure (name id1 ...) ((id2 expr) ...)) syntax 489
(define-syntax keyword expr) syntax 292
(define-top-level-syntax symbol obj) procedure 123
(define-top-level-syntax symbol obj env) procedure 123
(define-top-level-value symbol obj)  procedure 121
(define-top-level-value symbol obj env)  procedure 121
(define-values formals expr)  syntax 118
(delay expr)  syntax 128
(delete-directory path)  procedure 291
(delete-directory path error?)  procedure 291
(delete-file path)  procedure 290
(delete-file path error?)  procedure 290
(denominator rat)  procedure 286
(directory-list path)  procedure 288
(directory-separator)  procedure 292
(directory-separator? char)  procedure 292
(disable-interrupts)  procedure 359
(display obj)  procedure 285
(display obj textual-output-port)  procedure 285
(display-condition obj)  procedure 355
(display-condition obj textual-output-port)  procedure 355
(display-statistics)  procedure 421
(display-statistics textual-output-port)  procedure 421
(display-string string)  procedure 269
(display-string string textual-output-port)  procedure 269
(div x1 x2)  procedure 175
(div-and-mod x1 x2)  procedure 175
(div0 x1 x2)  procedure 176
(div0-and-mod0 x1 x2)  procedure 176
(do ((var init update) ...) (test result ...) expr ...)  syntax 115
(drop-prefix)  syntax 338
(dynamic-wind in body out)  procedure 131
(dynamic-wind critical? in body out)  procedure 131
(dynamic-wind in body out)  procedure 124
(ee-auto-indent)  global param 455
(ee-auto-paren-balance)  global param 456
(ee-bind-key key procedure)  procedure 457
(ee-common-identifiers)  global param 456
(ee-compose ecmd ...)  procedure 465
(ee-default-repeat)  global param 456
(ee-flash-parens)  global param 456
(ee-history-limit)  global param 456
(ee-noisy)  global param 456
(ee-paren-flash-delay)  global param 456
(ee-standard-indent)  global param 456
(ee-string-macro string)  procedure 466
else  syntax 112
(enable-arithmetic-left-associative)  thread param 392
(enable-cross-library-optimization)  thread param 392
(enable-error-source-expression)  thread param 392
(enable-interrupts)  procedure 359
(enable-object-backreferences)  global param 426
(enable-object-counts)  global param 425
enable-type-recovery
enable-unsafe-application
enable-unsafe-variable-reference
(endifanness symbol)
(engine-block)
(engine-return obj ...)
(enum-set->list enum-set)
(enum-set-complement enum-set)
(enum-set-constructor enum-set)
(enum-set-difference enum-set1 enum-set2)
(enum-set-indexer enum-set)
(enum-set-intersection enum-set1 enum-set2)
(enum-set-member? symbol enum-set)
(enum-set-projection enum-set1 enum-set2)
(enum-set-subset? enum-set1 enum-set2)
(enum-set-union enum-set1 enum-set2)
(enum-set-universe enum-set)
(enum-set=? enum-set1 enum-set2)
(enum-set? obj)
(enumerate ls)
(environment import-spec ...)
(environment-mutable? env)
(environment-symbols env)
(environment? obj)
(eof-object)
(eof-object? obj)
(eol-style symbol)
(ephemeron-cons obj1 obj2)
(ephemeron-pair? obj)
(eq-hashtable-cell hashtable key default)
(eq-hashtable-contains? hashtable key)
(eq-hashtable-delete! hashtable key)
(eq-hashtable-ephemeron? hashtable)
(eq-hashtable-ref hashtable key default)
(eq-hashtable-ref-cell hashtable key)
(eq-hashtable-set! hashtable key value)
(eq-hashtable-try-atomic-cell hashtable key default)
(eq-hashtable-update! hashtable key procedure default)
(eq-hashtable-weak? hashtable)
(eq-hashtable? obj)
(eq? obj1 obj2)
(equal-hash obj)
(equal? obj1 obj2)
(eqv? obj1 obj2)
(error who msg irritant ...)
(error-handling-mode symbol)
(error? obj)
(errorf who msg irritant ...)
(eval obj)
(eval obj env)
Summary of Forms

(eval obj environment)
procedure 136

(eval-syntax-expanders-when)
thread param 385

(eval-when situations form1 form2 ...)
syntax 381

(even? int)
procedure 174

(exact num)
procedure 180

(exact->inexact num)
procedure 181

(exact-integer-sqrt n)
procedure 184

(exact? num)
syntax 381

except
syntax 338

(exclusive-cond clause1 clause2 ...)
syntax 127

(exists procedure list1 list2 ...)
procedure 119

(exit obj ...)
procedure 410

(exit)
procedure 350

(exit obj)
procedure 350

exit-handler
procedure 350

(exp num)
procedure 184

(expand obj)
procedure 379

(expand obj env)
procedure 379

expand-omit-library-invocations
thread param 387

expand-output
thread param 396

(expand/optimize obj)
procedure 380

(expand/optimize obj env)
procedure 380

expand/optimize-output
thread param 396

(export export-spec ...)
syntax 483

(expression-editor)
module 455

(expt num1 num2)
procedure 179

(expt-mod int1 int2 int3)
procedure 236

(extend-syntax (name key ...) (pat fender template) ...)
syntax 483

(fasl-compressed)
thread param 288

(fasl-file ifn ofn)
procedure 288

(fasl-read binary-input-port)
procedure 287

(fasl-read binary-input-port situation)
procedure 287

(fasl-read binary-input-port situation externals)
procedure 287

(fasl-strip-options symbol ...)
syntax 377

(fasl-write obj binary-output-port)
procedure 286

(fasl-write obj binary-output-port external-pred)
procedure 286

(fasl-write obj binary-output-port external-pred omit-rtds?)
procedure 286

(fields)
syntax 331

(file-access-time path/port)
procedure 290

(file-access-time path/port follow?)
procedure 290

(file-buffer-size)
thread param 256

(file-change-time path/port)
procedure 290

(file-change-time path/port follow?)
procedure 290

(file-directory? path)
procedure 289

(file-directory? path follow?)
procedure 289

(file-exists? path)
procedure 289

(file-exists? path follow?)
procedure 289

(file-exists? path)
procedure 286

(file-length port)
procedure 250

(file-modification-time path/port)
procedure 290
### Summary of Forms

<table>
<thead>
<tr>
<th>Function</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(file-modification-time path/port follow?)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(file-options symbol ...)</code></td>
<td>syntax</td>
</tr>
<tr>
<td><code>(file-port? port)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(file-position port)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(file-position port pos)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(file-regular? path)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(file-regular? path follow?)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(file-symbolic-link? path)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(filter procedure list)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(find procedure list)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(finite? real)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fixnum-&gt;flonum fx)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fixnum-width)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fixnum? obj)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl* fl ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl+ fl ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl- fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl- fl1 fl2 fl3 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl-make-rectangular flonum1 flonum2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl/ fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl/ fl1 fl2 fl3 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&lt; flonum1 flonum2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&lt;= flonum1 flonum2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&lt;? fl1 fl2 fl3 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&lt;=? fl1 fl2 fl3 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl=? flonum1 flonum2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&gt; flonum1 flonum2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&gt;= flonum1 flonum2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&gt;? fl1 fl2 fl3 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fl&gt;=? fl1 fl2 fl3 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flabs fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flacos fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flasin fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flatan fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flceiling fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flfloor fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flfinite? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flinteger? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fldenominator fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fldiv fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fldiv-and-mod fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fldiv0 fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fldiv0-and-mod0 fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fleven? fl-int)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flexp fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flexpt fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(ffinite? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(ffloor fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(ffinfinite? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(ffinteger? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td>Procedure</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td><code>(fllog fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fllog fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flip flonum)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fmax fl1 fl2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fmin fl1 fl2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fmod fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fmod0 fl1 fl2)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flan? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flnegative? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flnonnegative? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flnonpositive? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flnonpositive? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flnumerator fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flodd? fl-int)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flonum-&gt;fixnum flonum)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flonum? obj)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(floor real)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flpositive? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flround fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flsin fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flsingle fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flsqrt fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fltan fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fltruncate fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fluid-let ((var expr) ...) body1 body2 ...)</code></td>
<td>syntax</td>
</tr>
<tr>
<td><code>(fluid-let-syntax ((keyword expr) ...) form1 form2 ...)</code></td>
<td>syntax</td>
</tr>
<tr>
<td><code>(flush-output-port)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flush-output-port output-port)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flush-output-port output-port)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector flonum ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector-&gt;list flvector)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector-copy flvector)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector-fill! flvector flonum)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector-length flvector)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector-ref flvector n)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector-set! flvector n flonum)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flvector? obj)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(flzero? fl)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fold-left procedure obj list1 list2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(fold-right procedure obj list1 list2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(for-all procedure list1 list2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(for-each procedure list1 list2 ...)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(force promise)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-address-name address)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-alignof type)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-alloc n)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-callable conv ... proc-exp (param-type ...) res-type)</code></td>
<td>syntax</td>
</tr>
<tr>
<td><code>(foreign-callable-code-object address)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-callable-entry-point code)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-entry entry-name)</code></td>
<td>procedure</td>
</tr>
<tr>
<td><code>(foreign-entry? entry-name)</code></td>
<td>procedure</td>
</tr>
</tbody>
</table>
(foreign-free address) procedure 75
(foreign-procedure conv ... entry-exp (param-type ...) res-type) syntax 59
(foreign-ref type address offset) procedure 75
(foreign-set! type address offset value) procedure 77
(foreign-sizeof type) procedure 77
(fork-thread thunk) procedure 468
(format format-string obj ...) procedure 275
(format #f format-string obj ...) procedure 275
(format #t format-string obj ...) procedure 275
(format textual-output-port format-string obj ...) procedure 275
(fprintf textual-output-port format-string obj ...) procedure 277
(free-identifier=? identifier1 identifier2) procedure 302
(fresh-line) procedure 270
(fresh-line textual-output-port) procedure 270
(ftype-&ref ftype-name (a ...) fptr-expr) syntax 85
(ftype-&ref ftype-name (a ...) fptr-expr index) syntax 85
(ftype-guardian ftype-name) syntax 474
(ftype-init-lock! ftype-name (a ...) fptr-expr) syntax 472
(ftype-init-lock! ftype-name (a ...) fptr-expr index) syntax 472
(ftype-lock! ftype-name (a ...) fpvecxp) syntax 472
(ftype-locked-decr! ftype-name (a ...) fptr-expr) syntax 473
(ftype-locked-decr! ftype-name (a ...) fptr-expr index) syntax 473
(ftype-locked-incr! ftype-name (a ...) fptr-expr) syntax 473
(ftype-locked-incr! ftype-name (a ...) fptr-expr index) syntax 473
(ftype-pointer->sexpr fptr) procedure 89
(ftype-pointer-address fptr) procedure 84
(ftype-pointer-fptr fptr) procedure 88
(ftype-pointer-null? fptr) syntax 85
(ftype-pointer=? fptr fptr1 fptr2) syntax 85
(ftype-pointer? obj) syntax 84
(ftype-pointer? ftype-name obj) syntax 84
(ftype-ref ftype-name (a ...) fptr-expr) syntax 86
(ftype-ref ftype-name (a ...) fptr-expr index) syntax 86
(ftype-set! ftype-name (a ...) fptr-expr val-expr) syntax 86
(ftype-set! ftype-name (a ...) fptr-expr index val-expr) syntax 86
(ftype-sizeof ftype-name) syntax 82
(ftype-spin-lock! ftype-name (a ...) fptr-expr) syntax 472
(ftype-spin-lock! ftype-name (a ...) fptr-expr index) syntax 472
(ftype-unlock! ftype-name (a ...) fptr-expr) syntax 472
(ftype-unlock! ftype-name (a ...) fptr-expr index) syntax 472
(fx* fixnum ...) procedure 211
(fx* f1 f2 f3) procedure 195
(fx*/carry f1 f2 f3) procedure 197
(fx*/wraparound fixnum ...) procedure 218
(fx+ fixnum ...) procedure 216
(fx+ f1 f2 f3) procedure 195
(fx+/carry f1 f2 f3) procedure 197
(fx+/wraparound fixnum ...) procedure 218
### Summary of Forms

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(fx- fixnum1 fixnum2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx- fx)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx- fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx-/carry fx1 fx2 fx3)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx/-wraparound fixnum ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx/ fixnum1 fixnum2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx1+ fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx1- fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx&lt; fixnum1 fixnum2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx&lt;= fixnum1 fixnum2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx&lt;? fix1 fx2 fx3 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx?&gt; fix1 fx2 fx3 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx&gt;= fixnum1 fixnum2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fx&gt;? fix1 fx2 fx3 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxabs fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxand fx ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxarithmetic-shift fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxarithmetic-shift-left fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxarithmetic-shift-right fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxbits-count fx)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxbits-field fx1 fx2 fx3)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxbits-set? fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxcopy-bit fx1 fx2 fx3)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxcopy-bit-field fx1 fx2 fx3 fx4)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxdiv fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxdiv-and-mod fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxdiv0 fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxdiv0-and-mod0 fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxeven? fx)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxfirst-bit-set fx)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxif fx1 fx2 fx3)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxior fix fx ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlength fx)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogand fixnum ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogbit0 index fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogbit1 index fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogbit? index fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogior fixnum ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlognot fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogor fixnum ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogtest fixnum1 fixnum2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxlogxor fixnum ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxmax fx1 fx2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxmin fx1 fx2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxmod fx1 fx2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(fxmod0 fx1 fx2)</td>
<td>procedure</td>
</tr>
</tbody>
</table>
Summary of Forms

(fpmodulo fixnum1 fixnum2) procedure 219
(fpnegative? fx) procedure 194
(fpnonnegative? fixnum) procedure 216
(fpnonpositive? fixnum) procedure 216
(fpnot fx) procedure 197
(fpodd? fx) procedure 194
(fppopulation fixnum) procedure 232
(fppopulation16 fixnum) procedure 232
(fppopulation32 fixnum) procedure 232
(fppositive? fx) procedure 194
(fpquotient fixnum1 fixnum2 ...) procedure 218
(fpremainder fixnum1 fixnum2) procedure 218
(fpreverse-bit-field fx1 fx2 fx3) procedure 202
(fprotate-bit-field fx1 fx2 fx3 fx4) procedure 201
(fpshift-left fixnum count) procedure 231
(fpshift-left/wraparound fixnum ...) procedure 218
(fpshift-right fixnum count) procedure 232
(fpshift-right fixnum count) procedure 232
(fpshift vector fixnum ...) procedure 156
(fpvectore->list fxvector) procedure 157
(fpvectore-copy fxvector) procedure 158
(fpvectore-fill! fxvector fixnum) procedure 157
(fpvectore-length fxvector) procedure 156
(fpvectore-ref fxvector n) procedure 156
(fpvectore-set! fxvector n fixnum) procedure 157
(fpvectore? obj) procedure 155
(fpxor fx ...) procedure 197
(fpxzero? fx) procedure 194
(gcd int ...) procedure 179

generate-allocation-counts thread param 427
(generate-covin-files thread param 402
(generate-inspector-information thread param 391
(generate-instruction-counts thread param 427
(generate-interrupt-trap thread param 390
(generate-procedure-source-information thread param 391
(generate-profile-forms thread param 402
(generate-temporaries list) procedure 310
(generate-wpo-files thread param 392
(gensym) procedure 170
(gensym pretty-name) procedure 170
(gensym pretty-name unique-name) procedure 170
(gensym->unique-string gensym) procedure 172
(gensym-count thread param 172
(gensym-prefix thread param 172
(gensym? obj) procedure 172
(get-bytevector-all binary-input-port) procedure 275
(get-bytevector-n binary-input-port n) procedure 274
(get-bytevector-n! binary-input-port bytevector start n) procedure 274
(get-bytevector-some binary-input-port) procedure 275
(get-bytevector-some! binary-input-port bytevector start n) procedure 260
<table>
<thead>
<tr>
<th>Form</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(get-char)</td>
<td>procedure 275</td>
</tr>
<tr>
<td>(get-datum)</td>
<td>procedure 278</td>
</tr>
<tr>
<td>(get-datum/annotations)</td>
<td>procedure 348</td>
</tr>
<tr>
<td>(get-hash-table)</td>
<td>procedure 482</td>
</tr>
<tr>
<td>(get-initial-thread)</td>
<td>procedure 468</td>
</tr>
<tr>
<td>(get-line)</td>
<td>procedure 277</td>
</tr>
<tr>
<td>(get-mode)</td>
<td>procedure 291</td>
</tr>
<tr>
<td>(get-output-string)</td>
<td>procedure 255</td>
</tr>
<tr>
<td>(get-process-id)</td>
<td>procedure 434</td>
</tr>
<tr>
<td>(get-registry)</td>
<td>procedure 434</td>
</tr>
<tr>
<td>(get-source-table!)</td>
<td>procedure 351</td>
</tr>
<tr>
<td>(get-string-all)</td>
<td>procedure 277</td>
</tr>
<tr>
<td>(get-string-n)</td>
<td>procedure 276</td>
</tr>
<tr>
<td>(get-string-n!)</td>
<td>procedure 276</td>
</tr>
<tr>
<td>(get-string-some)</td>
<td>procedure 259</td>
</tr>
<tr>
<td>(get-string-some!)</td>
<td>procedure 259</td>
</tr>
<tr>
<td>(get-thread-id)</td>
<td>procedure 468</td>
</tr>
<tr>
<td>(get-u8)</td>
<td>procedure 274</td>
</tr>
<tr>
<td>(getenv)</td>
<td>procedure 434</td>
</tr>
<tr>
<td>(getprop)</td>
<td>procedure 173</td>
</tr>
<tr>
<td>(greatest-fixnum)</td>
<td>procedure 193</td>
</tr>
<tr>
<td>(guard)</td>
<td>syntax 361</td>
</tr>
<tr>
<td>(guardian?)</td>
<td>procedure 450</td>
</tr>
<tr>
<td>(hash-table-for-each)</td>
<td>procedure 482</td>
</tr>
<tr>
<td>(hash-table-map)</td>
<td>procedure 482</td>
</tr>
<tr>
<td>(hash-table?)</td>
<td>procedure 481</td>
</tr>
<tr>
<td>(hashtable-cell)</td>
<td>procedure 176</td>
</tr>
<tr>
<td>(hashtable-cells)</td>
<td>procedure 179</td>
</tr>
<tr>
<td>(hashtable-clear!)</td>
<td>procedure 249</td>
</tr>
<tr>
<td>(hashtable-clear! size)</td>
<td>procedure 249</td>
</tr>
<tr>
<td>(hashtable-contains?)</td>
<td>procedure 246</td>
</tr>
<tr>
<td>(hashtable-copy)</td>
<td>procedure 248</td>
</tr>
<tr>
<td>(hashtable-copy size)</td>
<td>procedure 248</td>
</tr>
<tr>
<td>(hashtable-delete!)</td>
<td>procedure 248</td>
</tr>
<tr>
<td>(hashtable-entries)</td>
<td>procedure 178</td>
</tr>
<tr>
<td>(hashtable-entries size)</td>
<td>procedure 178</td>
</tr>
<tr>
<td>(hashtable-entries mutable?)</td>
<td>procedure 250</td>
</tr>
<tr>
<td>(hashtable-ephemeron?)</td>
<td>procedure 180</td>
</tr>
<tr>
<td>(hashtable-equivalence-function)</td>
<td>procedure 245</td>
</tr>
<tr>
<td>(hashtable-hash-function)</td>
<td>procedure 245</td>
</tr>
<tr>
<td>(hashtable-keys)</td>
<td>procedure 177</td>
</tr>
<tr>
<td>(hashtable-keys size)</td>
<td>procedure 177</td>
</tr>
<tr>
<td>(hashtable-mutable?)</td>
<td>procedure 249</td>
</tr>
<tr>
<td>(hashtable-ref)</td>
<td>procedure 246</td>
</tr>
<tr>
<td>(hashtable-ref-cell)</td>
<td>procedure 177</td>
</tr>
</tbody>
</table>
Summary of Forms

(hashtable-set! hashtable key obj) procedure 246
(hashtable-size hashtable) procedure 248
(hashtable-update! hashtable key procedure default) procedure 247
(hashtable-values hashtable) procedure 178
(hashtable-values hashtable size) procedure 178
(hashtable-weak? obj) procedure 180
(hashtable? obj) procedure 155

heap-reserve-ratio global param 442
(i/o-decoding-error? obj) procedure 375
(i/o-encoding-error-char condition) procedure 376
(i/o-encoding-error? obj) procedure 376
(i/o-error-filename condition) procedure 373
(i/o-error-port condition) procedure 375
(i/o-error-position condition) procedure 372
(i/o-error? obj) procedure 371
(i/o-file-already-exists-error? obj) procedure 374
(i/o-file-does-not-exist-error? obj) procedure 374
(i/o-file-is-read-only-error? obj) procedure 374
(i/o-file-protection-error? obj) procedure 373
(i/o-filename-error? obj) procedure 373
(i/o-invalid-position-error? obj) procedure 372
(i/o-port-error? obj) procedure 375
(i/o-read-error? obj) procedure 372
(i/o-write-error? obj) procedure 372
(iconv-codec code-page) procedure 244
(identifier-syntax tmpl) syntax 297
(identifier-syntax (id1 tmpl1) (set! id2 e2) tmpl2)) syntax 297
(identifier? obj) procedure 301

ieee module 339
(if test consequent alternative) syntax 109
(if test consequent) syntax 109
(imag-part num) procedure 182
immutable syntax 331
(immutable-box? obj) procedure 169
(immutable-bytevector? obj) procedure 164
(immutable-string? obj) procedure 152
(immutable-vector? obj) procedure 154
(implementation-restriction-violation? obj) procedure 369
(implicit-exports #t) syntax 314
(implicit-exports #f) syntax 314
(import import-spec ...) syntax 308
import-notify thread param 311
(import-only import-spec ...) syntax 308
in-place-minimum-generation global param 442
(include path) syntax 326
(indirect-export id indirect-id ...) syntax 313
(inexact num) procedure 180
(inexact->exact num) procedure 181
(inexact? num) procedure 170
Summary of Forms

(infinite? real) procedure 174
(initial-bytes-allocated) procedure 422
(input-port-ready? input-port) procedure 261
(input-port? obj) procedure 270
(inspect obj) procedure 42
(inspect/object object) procedure 47
(integer->char n) procedure 215
(integer-length n) procedure 236
(integer-valued? obj) procedure 153
(integer? obj) procedure 151
(interaction-environment thread param 362
(interactive?) procedure 433
(internal-defines-as-letrec* thread param 118
(interpret obj) procedure 365
(interpret obj env) procedure 365
(invoke-library libref) procedure 315
(iota n) procedure 145
(irritants-condition? obj) procedure 368
(isqrt n) procedure 236
(keep-live v) procedure 442
(keyboard-interrupt-handler thread param 358
(lambda formals body ...) syntax 92
(last-pair list) procedure 144
(latin-1-c codec) procedure 259
(lcm int ...) procedure 179
(least-fixnum) procedure 193
(length list) procedure 159
(let ((var expr) ...) body1 body2 ...) syntax 95
(let name ((var expr) ...) body1 body2 ...) syntax 114
(let* ((var expr) ...) body1 body2 ...) syntax 96
(let**-values ((formals expr) ...) body1 body2 ...) syntax 99
(let-syntax ((keyword expr) ...) form1 form2 ...) syntax 293
(let-values ((formals expr) ...) body1 body2 ...) syntax 99
(letrec ((var expr) ...) body1 body2 ...) syntax 97
(letrec* ((var expr) ...) body1 body2 ...) syntax 98
(letrec-syntax ((keyword expr) ...) form1 form2 ...) syntax 293
(lexical-violation? obj) procedure 370
(library name exports imports library-body) syntax 306
(library-directories thread param 316
(library-exports libref) procedure 318
(library-extensions thread param 316
(library-list) procedure 318
(library-object-filename libref) procedure 318
(library-requirements libref) procedure 318
(library-requirements libref options) procedure 318
(library-requirements-options symbol ...) syntax 319
(library-search-handler thread param 317
(library-timestamp-mode thread param 317
(library-version libref) procedure 318
(list obj ...) procedure 158
### Summary of Forms

<table>
<thead>
<tr>
<th>Function</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>(list* obj ... final-obj)</td>
<td>145</td>
</tr>
<tr>
<td>(list-&gt;flvector list)</td>
<td>160</td>
</tr>
<tr>
<td>(list-&gt;fxvector list)</td>
<td>154</td>
</tr>
<tr>
<td>(list-&gt;string list)</td>
<td>223</td>
</tr>
<tr>
<td>(list-&gt;vector list)</td>
<td>226</td>
</tr>
<tr>
<td>(list-assuming-immutable? v)</td>
<td>144</td>
</tr>
<tr>
<td>(list-copy list)</td>
<td>145</td>
</tr>
<tr>
<td>(list-head list n)</td>
<td>144</td>
</tr>
<tr>
<td>(list-ref list n)</td>
<td>159</td>
</tr>
<tr>
<td>(list-sort predicate list)</td>
<td>167</td>
</tr>
<tr>
<td>(list-tail list n)</td>
<td>160</td>
</tr>
<tr>
<td>(list? obj)</td>
<td>158</td>
</tr>
<tr>
<td>(literal-identifier=? identifier1 identifier2)</td>
<td>328</td>
</tr>
<tr>
<td>(load path)</td>
<td>366</td>
</tr>
<tr>
<td>(load path eval-proc)</td>
<td>366</td>
</tr>
<tr>
<td>(load-compiled-from-port input-port)</td>
<td>368</td>
</tr>
<tr>
<td>(load-compiled-from-port input-port externals)</td>
<td>368</td>
</tr>
<tr>
<td>(load-library path)</td>
<td>366</td>
</tr>
<tr>
<td>(load-library path eval-proc)</td>
<td>366</td>
</tr>
<tr>
<td>(load-program path)</td>
<td>367</td>
</tr>
<tr>
<td>(load-program path eval-proc)</td>
<td>367</td>
</tr>
<tr>
<td>(load-shared-object path)</td>
<td>94</td>
</tr>
<tr>
<td>(locate-source sfd pos)</td>
<td>348</td>
</tr>
<tr>
<td>(locate-source sfd pos use-cache?)</td>
<td>348</td>
</tr>
<tr>
<td>(locate-source-object-source source-object get-start? use-cache?)</td>
<td>349</td>
</tr>
<tr>
<td>(lock-object obj)</td>
<td>451</td>
</tr>
<tr>
<td>(locked-object? obj)</td>
<td>452</td>
</tr>
<tr>
<td>(log num)</td>
<td>184</td>
</tr>
<tr>
<td>(log num1 num2)</td>
<td>184</td>
</tr>
<tr>
<td>(logand int ...)</td>
<td>224</td>
</tr>
<tr>
<td>(logbit0 index int)</td>
<td>227</td>
</tr>
<tr>
<td>(logbit1 index int)</td>
<td>228</td>
</tr>
<tr>
<td>(logbit? index int)</td>
<td>226</td>
</tr>
<tr>
<td>(logior int ...)</td>
<td>225</td>
</tr>
<tr>
<td>(lognot int)</td>
<td>226</td>
</tr>
<tr>
<td>(logor int ...)</td>
<td>226</td>
</tr>
<tr>
<td>(logtest int1 int2)</td>
<td>227</td>
</tr>
<tr>
<td>(logxor int ...)</td>
<td>225</td>
</tr>
<tr>
<td>(lookahead-char textual-input-port)</td>
<td>275</td>
</tr>
<tr>
<td>(lookahead-u8 binary-input-port)</td>
<td>274</td>
</tr>
<tr>
<td>(machine-type)</td>
<td>378</td>
</tr>
<tr>
<td>(magnitude num)</td>
<td>183</td>
</tr>
<tr>
<td>(magnitude-squared num)</td>
<td>237</td>
</tr>
<tr>
<td>(make-annotation obj source-object stripped-obj)</td>
<td>345</td>
</tr>
<tr>
<td>(make-annotation obj source-object stripped-obj options)</td>
<td>345</td>
</tr>
<tr>
<td>(make-arity-wrapper-procedure proc arity-mask data)</td>
<td>209</td>
</tr>
<tr>
<td>(make-assertion-violation)</td>
<td>366</td>
</tr>
<tr>
<td>(make-boot-file output-filename base-boot-list input-filename ...)</td>
<td>376</td>
</tr>
<tr>
<td>(make-boot-header output-filename base-boot1 base-boot2...)</td>
<td>377</td>
</tr>
<tr>
<td>(make-bytevector n)</td>
<td>228</td>
</tr>
<tr>
<td>Function/Procedure</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>(make-bytevector n fill)</td>
<td>procedure</td>
</tr>
<tr>
<td>make-codec-buffer</td>
<td>thread param</td>
</tr>
<tr>
<td>(make-compile-time-value obj)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-condition)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-condition name)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-continuation-condition continuation)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-cost-center)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-custom-binary-input-port id r! gp sp! close)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-custom-binary-input/output-port id r! w! gp sp! close)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-custom-binary-output-port id r! gp sp! close)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-custom-textual-input-port id r! gp sp! close)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-custom-textual-input/output-port id r! w! gp sp! close)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-custom-textual-output-port id w! gp sp! close)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-date nsec sec min hour day mon year)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-date nsec sec min hour day mon year offset)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-engine thunk)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-enumeration symbol-list)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-ephemeron-eq-hashtable)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-ephemeron-eq-hashtable size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-ephemeron-eqv-hashtable size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-ephemeron-hashtable hash equiv?)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-ephemeron-hashtable hash equiv? size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-eq-hashtable)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-eq-hashtable size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-eqv-hashtable)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-eqv-hashtable size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-error)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-fxvector n)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-fxvector n fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-format-condition)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-ftype-pointer ftype-name expr)</td>
<td>syntax</td>
</tr>
<tr>
<td>(make-fxvector n)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-fxvector n fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-gardian)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-gardian ordered?)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-hash-table)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-hash-table weak?)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-hashable hash equiv?)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-hashtable hash equiv? size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-decoding-error pobj)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-encoding-error pobj cobj)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-error)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-file-already-exists-error filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-file-does-not-exist-error filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-file-is-read-only-error filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-file-protection-error filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-filename-error filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-invalid-position-error position)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-i/o-port-error pobj)</td>
<td>procedure</td>
</tr>
<tr>
<td>Procedure Name</td>
<td>Procedure Line</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| (make-i/o-read-error)                                                        | 372
| (make-i/o-write-error)                                                        | 372
| (make-immobile-bytevector n)                                                  | 452
| (make-immobile-bytevector n byte)                                             | 452
| (make-immobile-reference-bytevector n)                                        | 91
| (make-immobile-vector n)                                                      | 452
| (make-immobile-vector n obj)                                                  | 452
| (make-implementation-restriction-violation)                                   | 369
| (make-input-port handler input-buffer)                                        | 245
| (make-input/output-port handler input-buffer output-buffer)                  | 245
| (make-irritants-condition irritants)                                          | 368
| (make-lexical-violation)                                                      | 370
| (make-list n)                                                                 | 145
| (make-list n obj)                                                             | 145
| (make-message-condition message)                                              | 368
| (make-mutex)                                                                  | 469
| (make-mutex name)                                                             | 469
| (make-no-infinities-violation)                                                | 376
| (make-no-nans-violation)                                                      | 377
| (make-non-continuable-violation)                                              | 369
| (make-object-finder pred)                                                     | 53
| (make-object-finder pred g)                                                   | 53
| (make-object-finder pred x g)                                                 | 53
| (make-output-port handler output-buffer)                                      | 245
| (make-parameter object)                                                       | 429
| (make-parameter object procedure)                                             | 429
| (make-phantom-bytevector n)                                                   | 453
| (make-polar real1 real2)                                                      | 183
| (make-pseudo-random-generator)                                                | 233
| (make-record-constructor-descriptor rtd parent-rcd protocol)                  | 332
| (make-record-type type-name fields)                                           | 203
| (make-record-type parent-rtd type-name fields)                                | 203
| (make-record-type-descriptor name parent uid s? o? fields)                    | 208
| (make-record-type-descriptor name parent uid s? o? fields)                    | 331
| (make-rectangular real1 real2)                                                | 182
| (make-reference-bytevector n)                                                 | 91
| (make-serious-condition)                                                      | 366
| (make-source-condition form)                                                  | 354
| (make-source-file-descriptor obj binary-input-port)                          | 347
| (make-source-file-descriptor obj binary-input-port reset?)                    | 347
| (make-source-object sfd bfp efp)                                              | 346
| (make-source-object sfd bfp efp line column)                                  | 346
| (make-source-table)                                                           | 349
| (make-sstats cpu real bytes gc-count gc-cpu gc-real gc-bytes)                 | 424
| (make-string n)                                                               | 218
| (make-string n char)                                                          | 218
| (make-syntax-violation form subform)                                          | 370
| (make-thread-parameter object)                                                | 476
| (make-thread-parameter object procedure)                                      | 476
| (make-time type nsec sec)                                                     | 414
<table>
<thead>
<tr>
<th>Form</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>(make-transcoder codec)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-transcoder codec eol-style)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-transcoder codec eol-style error-handling-mode)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-undefined-violation)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-variable-transformer procedure)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-vector n)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-vector n obj)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-violation)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-warning)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-weak-eq-hashtable)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-weak-eq-hashtable size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-weak-eqv-hashtable)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-weak-eqv-hashtable size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-weak-hashtable hash equiv?)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-weak-hashtable hash equiv? size)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-who-condition who)</td>
<td>procedure</td>
</tr>
<tr>
<td>(make-wrapper-procedure proc arity-mask data)</td>
<td>procedure</td>
</tr>
<tr>
<td>(map procedure list1 list2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(max real1 real2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maximum-memory-bytes)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maybe-compile-file input-filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maybe-compile-file input-filename output-filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maybe-compile-library input-filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maybe-compile-library input-filename output-filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maybe-compile-program input-filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(maybe-compile-program input-filename output-filename)</td>
<td>procedure</td>
</tr>
<tr>
<td>(member obj list)</td>
<td>procedure</td>
</tr>
<tr>
<td>(memory-order-acquire)</td>
<td>procedure</td>
</tr>
<tr>
<td>(memory-order-release)</td>
<td>procedure</td>
</tr>
<tr>
<td>(memp procedure list)</td>
<td>procedure</td>
</tr>
<tr>
<td>(memq obj list)</td>
<td>procedure</td>
</tr>
<tr>
<td>(memv obj list)</td>
<td>procedure</td>
</tr>
<tr>
<td>(merge predicate list1 list2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(merge! predicate list1 list2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(message-condition? obj)</td>
<td>procedure</td>
</tr>
<tr>
<td>(meta . definition)</td>
<td>syntax</td>
</tr>
<tr>
<td>(meta-cond clause1 clause2 ...)</td>
<td>syntax</td>
</tr>
<tr>
<td>(min real1 real2 ...)</td>
<td>procedure</td>
</tr>
<tr>
<td>(mkdir path)</td>
<td>procedure</td>
</tr>
<tr>
<td>(mkdir path mode)</td>
<td>procedure</td>
</tr>
<tr>
<td>(mod x1 x2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(mod0 x1 x2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(module name interface defn ... init ...)</td>
<td>syntax</td>
</tr>
<tr>
<td>(module interface defn ... init ...)</td>
<td>syntax</td>
</tr>
<tr>
<td>(modulo int1 int2)</td>
<td>procedure</td>
</tr>
<tr>
<td>(most-negative-fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(most-positive-fixnum)</td>
<td>procedure</td>
</tr>
<tr>
<td>(mutable)</td>
<td>syntax</td>
</tr>
</tbody>
</table>
Summary of Forms

```
(mutable-box? obj)  procedure 169
(mutable-bytevector? obj)  procedure 164
(mutable-string? obj)  procedure 152
(mutable-vector? obj)  procedure 154
(mutex-acquire mutex)  procedure 469
(mutex-acquire mutex block?)  procedure 469
(mutex-name mutex)  procedure 470
(mutex-release mutex)  procedure 469
(mutex? obj)  procedure 469
(nan? real)  procedure 174
(native-endianness)  procedure 228
(native-eol-style)  procedure 260
(native-transcoder)  procedure 259
(negative? real)  procedure 173
(new-cafe)  procedure 407
(new-cafe eval-proc)  procedure 407
(newline)  procedure 285
(newline textual-output-port)  procedure 285
(no-infinities-violation? obj)  procedure 376
(no-nans-violation? obj)  procedure 377
(non-continuable-violation? obj)  procedure 369
(nongenerative)  syntax 331
(nonnegative? real)  procedure 237
(nonpositive? real)  procedure 237
(not obj)  procedure 110
(null-environment version)  procedure 137
(null? obj)  procedure 151
(number->string num)  procedure 238
(number->string num radix)  procedure 238
(number->string num radix precision)  procedure 238
(number->string num)  procedure 191
(number->string num radix)  procedure 191
(number->string num radix precision)  procedure 191
(number? obj)  procedure 151
(numerator rat)  procedure 181
(object->reference-address obj)  procedure 92
(object-backreferences)  procedure 426
(object-counts)  procedure 425
(oblist)  procedure 174
(odd? int)  procedure 174
only  syntax 338
opaque  syntax 333
(open-bytevector-input-port bytevector)  procedure 264
(open-bytevector-input-port bytevector ?transcoder)  procedure 264
(open-bytevector-output-port)  procedure 265
(open-bytevector-output-port ?transcoder)  procedure 265
(open-fd-input-port fd)  procedure 258
(open-fd-input-port fd b-mode)  procedure 258
(open-fd-input-port fd b-mode ?transcoder)  procedure 258
(open-fd-input/output-port fd)  procedure 270
```

Summary of Forms

(open-fd-input/output-port fd b-mode) procedure 270
(open-fd-input/output-port fd b-mode ?transcoder) procedure 270
(open-fd-output-port fd) procedure 267
(open-fd-output-port fd b-mode) procedure 267
(open-fd-output-port fd b-mode ?transcoder) procedure 267
(open-file-input-port path) procedure 262
(open-file-input-port path options) procedure 262
(open-file-input-port path options b-mode) procedure 262
(open-file-input-port path options b-mode ?transcoder) procedure 262
(open-file-input/output-port path) procedure 262
(open-file-input/output-port path options) procedure 262
(open-file-input/output-port path options b-mode) procedure 262
(open-file-input/output-port path options b-mode ?transcoder) procedure 262
(open-file-output-port path) procedure 257
(open-file-output-port path options) procedure 257
(open-file-output-port path options b-mode) procedure 257
(open-file-output-port path options b-mode ?transcoder) procedure 257
(open-file-output-port path) procedure 260
(open-file-output-port path options) procedure 260
(open-file-output-port path options b-mode) procedure 260
(open-file-output-port path options b-mode ?transcoder) procedure 260
(open-input-file path) procedure 254
(open-input-file path options) procedure 254
(open-input-file path) procedure 260
(open-input-output-file path) procedure 254
(open-input-output-file path options) procedure 254
(open-input-string string) procedure 254
(open-output-file path) procedure 255
(open-output-file path options) procedure 255
(open-output-file path) procedure 255
(open-output-string) procedure 255
(open-process-ports command) procedure 58
(open-process-ports command b-mode) procedure 58
(open-process-ports command b-mode ?transcoder) procedure 58
(open-source-file sfd) procedure 348
(open-string-input-port string) procedure 266
(open-string-output-port) procedure 266
optimize-level thread param 389
(or expr ...) syntax 110
(ormap procedure list1 list2 ...) procedure 129
(output-port-buffer-mode port) procedure 273
(output-port? obj) procedure 270
(pair? obj) procedure 151
(parameterize ((param expr) ...) body1 body2 ...) syntax 430
parent syntax 331
parent-rtd syntax 331
(pariah expr1 expr2 ...) syntax 397
(partition procedure list) procedure 164
(path-absolute? path) procedure 292
(path-build dir-path path) procedure 292
(path-extension path) procedure 292
(path-first path) procedure 292
(path-last path) procedure 292
(path-parent path) procedure 292
<table>
<thead>
<tr>
<th>Function/Procedure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(path-rest path)</td>
<td>procedure 292</td>
</tr>
<tr>
<td>(path-root path)</td>
<td>procedure 292</td>
</tr>
<tr>
<td>(pbchunk-convert-file in-path out-path c-paths c-names start-index)</td>
<td>procedure 378</td>
</tr>
<tr>
<td>(peek-char)</td>
<td>procedure 284</td>
</tr>
<tr>
<td>(peek-char textual-input-port)</td>
<td>procedure 284</td>
</tr>
<tr>
<td>(petite?)</td>
<td>procedure 433</td>
</tr>
<tr>
<td>(phantom-bytevector-length pbv)</td>
<td>procedure 453</td>
</tr>
<tr>
<td>(phantom-bytevector? obj)</td>
<td>procedure 453</td>
</tr>
<tr>
<td>(port-bol? port)</td>
<td>procedure 249</td>
</tr>
<tr>
<td>(port-closed? port)</td>
<td>procedure 249</td>
</tr>
<tr>
<td>(port-eof? input-port)</td>
<td>procedure 278</td>
</tr>
<tr>
<td>(port-file-compressed! port)</td>
<td>procedure 253</td>
</tr>
<tr>
<td>(port-file-descriptor port)</td>
<td>procedure 256</td>
</tr>
<tr>
<td>(port-handler port)</td>
<td>procedure 245</td>
</tr>
<tr>
<td>(port-has-port-length? port)</td>
<td>procedure 250</td>
</tr>
<tr>
<td>(port-has-port-nonblocking? port)</td>
<td>procedure 251</td>
</tr>
<tr>
<td>(port-has-port-position? port)</td>
<td>procedure 271</td>
</tr>
<tr>
<td>(port-has-set-port-length!? port)</td>
<td>procedure 251</td>
</tr>
<tr>
<td>(port-has-set-port-nonblocking!? port)</td>
<td>procedure 251</td>
</tr>
<tr>
<td>(port-has-set-port-position!? port)</td>
<td>procedure 272</td>
</tr>
<tr>
<td>(port-input-buffer input-port)</td>
<td>procedure 246</td>
</tr>
<tr>
<td>(port-input-count input-port)</td>
<td>procedure 247</td>
</tr>
<tr>
<td>(port-input-empty? input-port)</td>
<td>procedure 247</td>
</tr>
<tr>
<td>(port-input-size input-port)</td>
<td>procedure 246</td>
</tr>
<tr>
<td>(port-length port)</td>
<td>procedure 250</td>
</tr>
<tr>
<td>(port-name port)</td>
<td>procedure 250</td>
</tr>
<tr>
<td>(port-nonblocking? port)</td>
<td>procedure 251</td>
</tr>
<tr>
<td>(port-output-buffer output-port)</td>
<td>procedure 247</td>
</tr>
<tr>
<td>(port-output-count output-port)</td>
<td>procedure 248</td>
</tr>
<tr>
<td>(port-output-full? output-port)</td>
<td>procedure 248</td>
</tr>
<tr>
<td>(port-output-index output-port)</td>
<td>procedure 247</td>
</tr>
<tr>
<td>(port-output-size output-port)</td>
<td>procedure 247</td>
</tr>
<tr>
<td>(port-position port)</td>
<td>procedure 271</td>
</tr>
<tr>
<td>(port-transcoder port)</td>
<td>procedure 271</td>
</tr>
<tr>
<td>(port? obj)</td>
<td>procedure 270</td>
</tr>
<tr>
<td>(positive? real)</td>
<td>procedure 173</td>
</tr>
<tr>
<td>predicate</td>
<td>syntax 199</td>
</tr>
<tr>
<td>prefix</td>
<td>syntax 199</td>
</tr>
<tr>
<td>(pretty-file fn ofn)</td>
<td>procedure 272</td>
</tr>
<tr>
<td>(pretty-format sym)</td>
<td>procedure 272</td>
</tr>
<tr>
<td>(pretty-format sym fmt)</td>
<td>procedure 272</td>
</tr>
<tr>
<td>pretty-initial-indent</td>
<td>thread param 274</td>
</tr>
<tr>
<td>pretty-line-length</td>
<td>thread param 274</td>
</tr>
<tr>
<td>pretty-maximum-lines</td>
<td>thread param 275</td>
</tr>
<tr>
<td>pretty-one-line-limit</td>
<td>thread param 274</td>
</tr>
<tr>
<td>(pretty-print obj)</td>
<td>procedure 271</td>
</tr>
<tr>
<td>(pretty-print obj textual-output-port)</td>
<td>thread param 275</td>
</tr>
<tr>
<td>pretty-standard-indent</td>
<td>thread param 282</td>
</tr>
<tr>
<td>print-brackets</td>
<td>thread param 282</td>
</tr>
</tbody>
</table>
Summary of Forms

print-char-name  thread param 279
print-extended-identifiers  thread param 283
print-gensym  thread param 282
print-graph  thread param 280
print-length  thread param 280
print-level  thread param 280
print-positive-exponent-sign  thread param 285
print-precision  thread param 284
print-radix  thread param 281
print-record  thread param 203
print-select-flonum-exponential-format  thread param 285
print-subnormal-precision  thread param 284
print-unicode  thread param 285
print-vector-length  thread param 284
(printf format-string obj ...)  procedure 277
(expr expr1 ...)  syntax 107
(procedure-arity-mask proc)  procedure 208
(procedure-known-single-valued? proc)  procedure 211
(procedure? obj)  procedure 155
(process command)  procedure 58
(profile source-object)  syntax 402
(profile-clear)  procedure 402
(profile-clear-database)  procedure 407
(profile-dump)  procedure 403
(profile-dump-data path)  procedure 406
(profile-dump-data path dump)  procedure 406
(profile-dump-html)  procedure 404
(profile-dump-html prefix)  procedure 404
(profile-dump-html prefix dump)  procedure 404
(profile-dump-list)  procedure 405
(profile-dump-list warn?)  procedure 405
(profile-dump-list warn? dump)  procedure 405
(profile-line-number-color)  thread param 405
(profile-load-data path ...)  procedure 406
(profile-palette)  thread param 404
(profile-query-weight obj)  procedure 407
(profile-release-counters)  procedure 403
(property-list symbol)  procedure 174
protocol  syntax 331
(pseudo-random-generator->vector prgen)  procedure 234
(pseudo-random-generator-next! prgen)  procedure 234
(pseudo-random-generator-next! prgen below-int)  procedure 234
(pseudo-random-generator-seed! prgen seed-int)  procedure 234
(pseudo-random-generator? val)  procedure 233
(put-bytevector-binary-output-port bytevector)  procedure 279
(put-bytevector-binary-output-port bytevector start)  procedure 279
(put-bytevector-binary-output-port bytevector start n)  procedure 279
(put-bytevector-some binary-output-port bytevector)  procedure 268
(put-bytevector-some binary-output-port bytevector start)  procedure 268
(put-bytevector-some binary-output-port bytevector start n)  procedure 268
Summary of Forms

(put-char textual-output-port char) procedure 279
(put-datum textual-output-port obj) procedure 279
(put-hash-table! ht k v) procedure 482
(put-registry! key val) procedure 434
(put-source-table textual-output-port source-table) procedure 351
(put-string textual-output-port string) procedure 279
(put-string textual-output-port string start n) procedure 279
(put-string some textual-output-port string) procedure 268
(put-string some textual-output-port string start n) procedure 268
(put-u8 binary-output-port octet) procedure 278
(putenv key value) procedure 434
(putprop symbol key value) procedure 173
(quasiquote obj ...) syntax 142
(quasisyntax template ...) syntax 305
(quote obj) syntax 141
(quotient int1 int2) procedure 179
r5rs module 339
r5rs-syntax module 339
(raise obj) procedure 357
(raise-continuable obj) procedure 357
(random real) procedure 233
random-seed thread-param 238
(rational-valued? obj) procedure 153
(rational? obj) procedure 151
(rationalize real1 real2) procedure 181
(ratnum? obj) procedure 215
(read) procedure 284
(read textual-input-port) procedure 284
(read-char) procedure 284
(read-char textual-input-port) procedure 284
(read-token) procedure 262
(read-token textual-input-port) procedure 262
(read-token textual-input-port sfd bfp) procedure 262
(real->flonum real) procedure 211
(real-part num) procedure 182
(real-time) procedure 421
(real-valued? obj) procedure 153
(real? obj) procedure 151
(rec var expr) syntax 119
(record-accessor rtd idx) procedure 334
(record-case expr clause1 clause2 ...) syntax 128
(record-constructor rcd) procedure 205
(record-constructor rtd) procedure 205
(record-constructor rcd) procedure 333
(record-constructor-descriptor record-name) syntax 333
(record-constructor-descriptor? obj) procedure 143
(record-equal-procedure record1 record2) procedure 191
(record-field-accessible? rtd field-id) procedure 205
(record-field-accessor rtd field-id) procedure 205
(record-field-mutable? rtd field-id) procedure 206
(record-field-mutable? rtd idx) procedure 338
(record-field-mutator rtd field-id) procedure 205
(record-hash-procedure record) procedure 191
(record-instance? obj rtd) procedure 207
(record-mutator rtd idx) procedure 334
(record-predicate rtd) procedure 333
(record-reader name) procedure 200
(record-reader rtd) procedure 200
(record-reader name rtd) procedure 200
(record-reader name #f) procedure 200
(record-reader rtd #f) procedure 200
(record-rtd record) procedure 338
(record-type-descriptor rec) procedure 208
(record-type-descriptor record-name) syntax 333
(record-type-descriptor? obj) procedure 332
(record-type-equal-procedure rtd equal-proc) procedure 190
(record-type-equal-procedure rtd) procedure 190
(record-type-field-decls rtd) procedure 207
(record-type-field-names rtd) procedure 206
(record-type-field-names rtd) procedure 337
(record-type-generative? rtd) procedure 337
(record-type-has-named-fields? rtd) procedure 208
(record-type-hash-procedure rtd hash-proc) procedure 191
(record-type-hash-procedure rtd) procedure 191
(record-type-name rtd) procedure 206
(record-type-name rtd) procedure 336
(record-type-opaque? rtd) procedure 337
(record-type-parent rtd) procedure 208
(record-type-sealed? rtd) procedure 337
(record-type-symbol rtd) procedure 206
(record-type-uid rtd) procedure 336
(record-writer rtd) procedure 201
(record-writer rtd procedure) procedure 201
(record? obj) procedure 207
(record? obj rtd) procedure 207
(record? obj) procedure 338
(reference-address->object addr) procedure 92
(reference-address->object addr) procedure 92
(reference-bytevector? obj) procedure 91
(register-signal-handler sig procedure) procedure 360
release-minimum-generation global param 441
(remainder int1 int2) procedure 175
(remove obj list) procedure 163
(remove! obj list) procedure 146
(remove-foreign-entry entry-name) procedure 96
(remove-hash-table! ht k) procedure 482
(remove-registry! key) procedure 434
(remp procedure list) procedure 163
Summary of Forms

(remprop symbol key) procedure 174
(remq obj list) procedure 163
(remq! obj list) procedure 146
(remv obj list) procedure 163
(remv! obj list) procedure 146
rename syntax 338
(rename-file old-pathname new-pathname) procedure 291
require-nongenerative-clause thread param 188
(reset) procedure 410
(reset-cost-center! cost-center) procedure 429
reset-handler thread param 410
(reset-maximum-memory-bytes!) procedure 423
(reverse list) procedure 161
(reverse! list) procedure 147
(revisit path) procedure 369
(revisit-compiled-from-port input-port) procedure 368
(round real) procedure 178
run-cp0 thread param 393
(s8-list->bytevector list) procedure 162
(sc-expand obj) procedure 379
(sc-expand obj env) procedure 379
scheme module 339
(scheme-environment) procedure 362
(scheme-pre-release) procedure 433
scheme-program global param 411
(scheme-report-environment version) procedure 137
scheme-script global param 411
scheme-start global param 411
(scheme-version) procedure 432
(scheme-version show-pre-release?) procedure 432
(scheme-version-number) procedure 433
sealed syntax 331
self-evaluating-vectors thread param 155
(serious-condition? obj) procedure 366
(set! var expr) syntax 102
(set-binary-port-input-buffer! binary-input-port bytevector) procedure 246
(set-binary-port-input-index! binary-input-port n) procedure 246
(set-binary-port-input-size! binary-input-port n) procedure 246
(set-binary-port-output-buffer! binary-output-port bytevector) procedure 248
(set-binary-port-output-index! output-port n) procedure 248
(set-binary-port-output-size! output-port n) procedure 248
(set-box! box obj) procedure 169
(set-car! pair obj) procedure 157
(set-cdr! pair obj) procedure 157
(set-phantom-bytevector-length! pbv n) procedure 453
(set-port-bol! output-port obj) procedure 249
(set-port-eof! input-port obj) procedure 249
(set-port-input-buffer! input-port x) procedure 246
(set-port-input-index! input-port n) procedure 246
(set-port-input-size! input-port n) procedure 246
<table>
<thead>
<tr>
<th>Procedure Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>(set-port-length! port len)</td>
<td>251</td>
</tr>
<tr>
<td>(set-port-name! port obj)</td>
<td>250</td>
</tr>
<tr>
<td>(set-port-nonblocking! port obj)</td>
<td>251</td>
</tr>
<tr>
<td>(set-port-output-buffer! output-port x)</td>
<td>248</td>
</tr>
<tr>
<td>(set-port-output-index! output-port n)</td>
<td>248</td>
</tr>
<tr>
<td>(set-port-output-size! output-port n)</td>
<td>248</td>
</tr>
<tr>
<td>(set-port-position! port pos)</td>
<td>272</td>
</tr>
<tr>
<td>(set-sstats-bytes! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-sstats-cpu! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-sstats-gc-bytes! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-sstats-gc-count! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-sstats-gc-cpu! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-sstats-gc-real! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-sstats-real! s new-value)</td>
<td>424</td>
</tr>
<tr>
<td>(set-textual-port-input-buffer! textual-input-port string)</td>
<td>246</td>
</tr>
<tr>
<td>(set-textual-port-input-index! textual-input-port n)</td>
<td>246</td>
</tr>
<tr>
<td>(set-textual-port-input-size! textual-input-port n)</td>
<td>246</td>
</tr>
<tr>
<td>(set-textual-port-output-buffer! textual-output-port string)</td>
<td>248</td>
</tr>
<tr>
<td>(set-textual-port-output-index! textual-output-port n)</td>
<td>248</td>
</tr>
<tr>
<td>(set-textual-port-output-size! textual-output-port n)</td>
<td>248</td>
</tr>
<tr>
<td>(set-time-nanosecond! time nsec)</td>
<td>415</td>
</tr>
<tr>
<td>(set-time-second! time sec)</td>
<td>415</td>
</tr>
<tr>
<td>(set-time-type! time type)</td>
<td>415</td>
</tr>
<tr>
<td>(set-top-level-value! symbol obj)</td>
<td>122</td>
</tr>
<tr>
<td>(set-top-level-value! symbol obj env)</td>
<td>122</td>
</tr>
<tr>
<td>(set-virtual-register! k x)</td>
<td>432</td>
</tr>
<tr>
<td>(set-wraper-procedure-data! w-proc data)</td>
<td>210</td>
</tr>
<tr>
<td>(set-wraper-procedure-procedure! w-proc proc)</td>
<td>210</td>
</tr>
<tr>
<td>(simple-conditions condition)</td>
<td>363</td>
</tr>
<tr>
<td>(sin num)</td>
<td>185</td>
</tr>
<tr>
<td>(sinh num)</td>
<td>238</td>
</tr>
<tr>
<td>(sint-list-&gt;bytevector list eness size)</td>
<td>239</td>
</tr>
<tr>
<td>(sleep time)</td>
<td>420</td>
</tr>
<tr>
<td>(sort predicate list)</td>
<td>176</td>
</tr>
<tr>
<td>(sort! predicate list)</td>
<td>176</td>
</tr>
<tr>
<td>(source-condition-form condition)</td>
<td>354</td>
</tr>
<tr>
<td>(source-condition? obj)</td>
<td>354</td>
</tr>
<tr>
<td>source-directories</td>
<td>388</td>
</tr>
<tr>
<td>(source-file-descriptor path checksum)</td>
<td>347</td>
</tr>
<tr>
<td>(source-file-descriptor-checksum sfd)</td>
<td>347</td>
</tr>
<tr>
<td>(source-file-descriptor-path sfd)</td>
<td>347</td>
</tr>
<tr>
<td>(source-file-descriptor? obj)</td>
<td>347</td>
</tr>
<tr>
<td>(source-object-bfp source-object)</td>
<td>346</td>
</tr>
<tr>
<td>(source-object-column source-object)</td>
<td>347</td>
</tr>
<tr>
<td>(source-object-efp source-object)</td>
<td>346</td>
</tr>
<tr>
<td>(source-object-line source-object)</td>
<td>346</td>
</tr>
<tr>
<td>(source-object-sfd source-object)</td>
<td>346</td>
</tr>
<tr>
<td>(source-object? obj)</td>
<td>346</td>
</tr>
<tr>
<td>(source-table-cell source-table source-object default)</td>
<td>350</td>
</tr>
</tbody>
</table>
Summary of Forms

(source-table-contains? source-table source-object) procedure 350
(source-table-delete! source-table source-object) procedure 350
(source-table-dump source-table) procedure 404
(source-table-ref source-table source-object default) procedure 350
(source-table-set! source-table source-object obj) procedure 350
(source-table-size source-table) procedure 350
(source-table? obj) procedure 350
(sqrt num) procedure 183
(sstats-bytes s) procedure 424
(sstats-cpu s) procedure 424
(sstats-difference s1 s2) procedure 425
(sstats-gc-bytes s) procedure 424
(sstats-gc-count s) procedure 424
(sstats-gc-cpu s) procedure 424
(sstats-gc-real s) procedure 424
(sstats-print s) procedure 425
(sstats-print s textual-output-port) procedure 425
(sstats-real s) procedure 424
(sstats? obj) procedure 424
(standard-error-port) procedure 268
(standard-error-port b-mode) procedure 268
(standard-error-port b-mode ?transcoder) procedure 268
(standard-error-port) procedure 264
(standard-input-port) procedure 259
(standard-input-port b-mode) procedure 259
(standard-input-port b-mode ?transcoder) procedure 259
(standard-output-port) procedure 267
(standard-output-port b-mode) procedure 267
(standard-output-port b-mode ?transcoder) procedure 267
(standard-output-port) procedure 264
(statistics) procedure 423
(stencil-vector mask obj ...) procedure 165
(stencil-vector-length stencil-vector) procedure 165
(stencil-vector-mask stencil-vector) procedure 165
(stencil-vector-mask-width) procedure 165
(stencil-vector-ref stencil-vector n) procedure 166
(stencil-vector-set! stencil-vector n obj) procedure 166
(stencil-vector-truncate! stencil-vector mask) procedure 167
(stencil-vector-update stencil-vector remove-bits add-bits obj ...) procedure 167
(stencil-vector? obj) procedure 165
(string char ...) procedure 218
(string->bytevector string transcoder) procedure 287
(string->immutable-string string) procedure 152
(string->list string) procedure 222
(string->multibyte code-page string) procedure 274
(string->number string) procedure 238
(string->number string radix) procedure 238
(string->number string) procedure 191
(string->number string radix) procedure 191
(string->symbol string)
procedure 242

(string->uninterned-symbol str)
procedure 172

(string->utf16 string)
procedure 287

(string->utf16 string endianness)
procedure 287

(string->utf32 string)
procedure 287

(string->utf32 string endianness)
procedure 287

(string->utf8 string)
procedure 287

(string-append string ...)
procedure 219

(string-append-immutable string ...)
procedure 152

(string-ci-hash string)
procedure 245

(string-ci<=? string1 string2 string3 ...)
procedure 150

(string-ci<=? string1 string2 string3 ...)
procedure 217

(string-ci<=? string1 string2 string3 ...)
procedure 150

(string-ci=? string1 string2 string3 ...)
procedure 217

(string-ci=? string1 string2 string3 ...)
procedure 150

(string-ci=? string1 string2 string3 ...)
procedure 217

(string-ci=? string1 string2 string3 ...)
procedure 150

(string-ci=? string1 string2 string3 ...)
procedure 217

(string-ci=? string1 string2 string3 ...)
procedure 150

(string-ci=? string1 string2 string3 ...)
procedure 217

(string-ci=? string1 string2 string3 ...)
procedure 150

(string-ci=>? string1 string2 string3 ...)
procedure 150

(string-ci=>? string1 string2 string3 ...)
procedure 217

(string-ci=>? string1 string2 string3 ...)
procedure 150

(string-ci=>? string1 string2 string3 ...)
procedure 217

(string-ci=>? string1 string2 string3 ...)
procedure 150

(string-ci=>? string1 string2 string3 ...)
procedure 217

(string-ci=>? string1 string2 string3 ...)
procedure 150

(string-ci=>? string1 string2 string3 ...)
procedure 217

(string-copy string)
procedure 219

(string-copy! src src-start dst dst-start n)
procedure 151

(string-downcase string)
procedure 221

(string-fill! string char)
procedure 220

(string-foldcase string)
procedure 221

(string-for-each procedure string1 string2 ...)
procedure 122

(string-grapheme-count string)
procedure 153

(string-grapheme-count string start)
procedure 153

(string-grapheme-count string start end)
procedure 153

(string-grapheme-span string start)
procedure 152

(string-grapheme-span string start end)
procedure 152

(string-hash string)
procedure 152

(string-length string)
procedure 218

(string-normalize-nfc string)
procedure 222

(string-normalize-nfd string)
procedure 222

(string-normalize-nfkc string)
procedure 222

(string-normalize-nfkd string)
procedure 222

(string-ref string n)
procedure 218

(string-set! string n char)
procedure 219

(string-titlecase string)
procedure 221

(string-truncate! string n)
procedure 151

(string-upcase string)
procedure 221

(string<=? string1 string2 string3 ...)
procedure 150

(string<=? string1 string2 string3 ...)
procedure 216

(string<=? string1 string2 string3 ...)
procedure 150

(string<=? string1 string2 string3 ...)
procedure 216

(string=>? string1 string2 string3 ...)
procedure 150

(string=>? string1 string2 string3 ...)
procedure 216

(string=>? string1 string2 string3 ...)
procedure 150

(string=>? string1 string2 string3 ...)
procedure 216
(string>? string₁ string₂ string₃ ...) procedure 150
(string>? string₁ string₂ string₃ ...) procedure 216
(string? obj) procedure 154
(strip-fasl-file input-path output-path options) procedure 314
(sub₁ num) procedure 235
subset-mode thread param 435
(subst new old tree) procedure 146
(subst! new old tree) procedure 146
(substq new old tree) procedure 146
(substq! new old tree) procedure 146
(substring string start end) procedure 220
(substring-fill! string start end char) procedure 151
(substv new old tree) procedure 146
(substv! new old tree) procedure 146
(subtract-duration time timeₐ) procedure 416
(subtract-duration! time timeₐ) procedure 416
suppress-greeting global param 412
(symbol->string symbol) procedure 242
(symbol-hash symbol) procedure 245
(symbol-hashtable-cell hashtable key default) procedure 186
(symbol-hashtable-contains? hashtable key) procedure 185
(symbol-hashtable-delete! hashtable key) procedure 187
(symbol-hashtable-ref hashtable key default) procedure 185
(symbol-hashtable-ref-cell hashtable key) procedure 187
(symbol-hashtable-set! hashtable key value) procedure 184
(symbol-hashtable-update! hashtable key procedure default) procedure 185
(symbol-hashtable? obj) procedure 184
(symbol=? symbol₁ symbol₂) procedure 242
(symbol? obj) procedure 154
(syntax template) syntax 300
(syntax->annotation obj) procedure 348
(syntax->datum obj) procedure 308
(syntax->list syntax-object) procedure 323
(syntax->vector syntax-object) procedure 324
(syntax-case expr (literal ...) clause ...) syntax 299
(syntax-error obj string ...) procedure 327
(syntax-object->datum obj) procedure 324
(syntax-rules (literal ...) clause ...) syntax 323
(syntax-rules (literal ...) clause ...) syntax 294
(syntax-violation who msg form) procedure 359
(syntax-violation who msg form subform) procedure 359
(syntax-violation-form condition) procedure 370
(syntax-violation-subform condition) procedure 370
(syntax-violation? obj) procedure 57
(system command) procedure 185
(tan num) procedure 185
(tanh num) procedure 238
(textual-port-input-buffer textual-input-port) procedure 246
(textual-port-input-count textual-input-port) procedure 247
(textual-port-input-index textual-input-port) procedure 246
Summary of Forms

(textual-port-input-size  textual-input-port) procedure 246
(textual-port-output-buffer  output-port) procedure 247
(textual-port-output-count  textual-output-port) procedure 248
(textual-port-output-index  output-port) procedure 247
(textual-port-output-size  output-port) procedure 247
(textual-port?  obj) procedure 270
(thread-condition?  obj) procedure 470
(thread-join  thread) procedure 468
(thread-preserve-ownership!) procedure 468
(thread-preserve-ownership!  thread) procedure 468
(thread?  obj) procedure 468
(threaded?) procedure 433
(time  expr) syntax 421
(time-difference  time1  time2) procedure 416
(time-difference!  time1  time2) procedure 416
(time-nanosecond  time) procedure 415
(time-second  time) procedure 415
(time-type  time) procedure 415
(time-utc->date  time) procedure 420
(time-utc->date  time offset) procedure 420
(time<=?  time1  time2) procedure 416
(time>?  time1  time2) procedure 416
(time=?  time1  time2) procedure 416
(time>=?  time1  time2) procedure 416
(time?  obj) procedure 415
timer-interrupt-handler thread param 359
(top-level-bound?  symbol) procedure 122
(top-level-bound?  symbol env) procedure 122
(top-level-mutable?  symbol) procedure 123
(top-level-mutable?  symbol env) procedure 123
(top-level-program  imports body) syntax 307
(top-level-syntax  symbol) procedure 124
(top-level-syntax  symbol env) procedure 124
(top-level-syntax?  symbol) procedure 125
(top-level-syntax?  symbol env) procedure 125
(top-level-value  symbol) procedure 122
(top-level-value  symbol env) procedure 122
(trace var1  var2  ...) syntax 36
(trace) syntax 36
(trace-case-lambda  name clause ...) syntax 34
(trace-define  var expr) syntax 38
(trace-define (var . idspec) body1 body2  ...) syntax 38
(trace-define-syntax  keyword expr) syntax 39
(trace-do ((var init update)  ...) (test result  ...) expr  ...) syntax 35
(trace-lambda  name formals body1 body2  ...) syntax 33
(trace-let  name ((var expr)  ...) body1 body2  ...) syntax 31
trace-output-port thread param 38
trace-print thread param 38
(transcoded-port  binary-port transcoder) procedure 271
<table>
<thead>
<tr>
<th>Function/Procedure</th>
<th>Category</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>transcoded-port-buffer-size</td>
<td>thread param</td>
<td>244</td>
</tr>
<tr>
<td>(transcoder-codec transcoder)</td>
<td>procedure</td>
<td>259</td>
</tr>
<tr>
<td>(transcoder-eol-style transcoder)</td>
<td>procedure</td>
<td>259</td>
</tr>
<tr>
<td>(transcoder-error-handling-mode transcoder)</td>
<td>procedure</td>
<td>259</td>
</tr>
<tr>
<td>(transcoder? obj)</td>
<td>procedure</td>
<td>244</td>
</tr>
<tr>
<td>(transcript-cafe path)</td>
<td>procedure</td>
<td>413</td>
</tr>
<tr>
<td>(transcript-off)</td>
<td>procedure</td>
<td>413</td>
</tr>
<tr>
<td>(transcript-on path)</td>
<td>procedure</td>
<td>413</td>
</tr>
<tr>
<td>(truncate real)</td>
<td>procedure</td>
<td>177</td>
</tr>
<tr>
<td>(truncate-file output-port)</td>
<td>procedure</td>
<td>269</td>
</tr>
<tr>
<td>(truncate-file output-port pos)</td>
<td>procedure</td>
<td>269</td>
</tr>
<tr>
<td>(truncate-port output-port)</td>
<td>procedure</td>
<td>269</td>
</tr>
<tr>
<td>(truncate-port output-port pos)</td>
<td>procedure</td>
<td>269</td>
</tr>
<tr>
<td>(type-descriptor name)</td>
<td>syntax</td>
<td>200</td>
</tr>
<tr>
<td>(u8-list-&gt;bytevector list)</td>
<td>procedure</td>
<td>232</td>
</tr>
<tr>
<td>(uint-list-&gt;bytevector list eness size)</td>
<td>procedure</td>
<td>239</td>
</tr>
<tr>
<td>(unbox box)</td>
<td>procedure</td>
<td>168</td>
</tr>
<tr>
<td>undefined-variable-warnings</td>
<td>thread param</td>
<td>396</td>
</tr>
<tr>
<td>(undefined-violation? obj)</td>
<td>procedure</td>
<td>371</td>
</tr>
<tr>
<td>(unget-char textual-input-port char)</td>
<td>procedure</td>
<td>260</td>
</tr>
<tr>
<td>(unget-u8 binary-input-port octet)</td>
<td>procedure</td>
<td>261</td>
</tr>
<tr>
<td>(uninterned-symbol? obj)</td>
<td>procedure</td>
<td>173</td>
</tr>
<tr>
<td>(unless test-expr expr1 expr2 ...)</td>
<td>syntax</td>
<td>112</td>
</tr>
<tr>
<td>(unlock-object obj)</td>
<td>procedure</td>
<td>451</td>
</tr>
<tr>
<td>(unquote obj ...)</td>
<td>syntax</td>
<td>142</td>
</tr>
<tr>
<td>(unquote-splicing obj ...)</td>
<td>syntax</td>
<td>142</td>
</tr>
<tr>
<td>(unread-char char)</td>
<td>procedure</td>
<td>260</td>
</tr>
<tr>
<td>(unread-char char textual-input-port)</td>
<td>procedure</td>
<td>260</td>
</tr>
<tr>
<td>(unregister-guardian guardian)</td>
<td>procedure</td>
<td>450</td>
</tr>
<tr>
<td>(unsyntax template ...)</td>
<td>syntax</td>
<td>305</td>
</tr>
<tr>
<td>(unsyntax-splicing template ...)</td>
<td>syntax</td>
<td>305</td>
</tr>
<tr>
<td>(untrace var1 var2 ...)</td>
<td>syntax</td>
<td>37</td>
</tr>
<tr>
<td>(untrace)</td>
<td>syntax</td>
<td>37</td>
</tr>
<tr>
<td>(utf-16-codec)</td>
<td>procedure</td>
<td>243</td>
</tr>
<tr>
<td>(utf-16-codec endianness)</td>
<td>procedure</td>
<td>243</td>
</tr>
<tr>
<td>(utf-16-codec)</td>
<td>procedure</td>
<td>243</td>
</tr>
<tr>
<td>(utf-16be-codec)</td>
<td>procedure</td>
<td>243</td>
</tr>
<tr>
<td>(utf-16le-codec)</td>
<td>procedure</td>
<td>243</td>
</tr>
<tr>
<td>(utf-8-codec)</td>
<td>procedure</td>
<td>259</td>
</tr>
<tr>
<td>(utf16-&gt;string bytevector endianness)</td>
<td>procedure</td>
<td>288</td>
</tr>
<tr>
<td>(utf16-&gt;string bytevector endianness-endianness-mandatory?)</td>
<td>procedure</td>
<td>288</td>
</tr>
<tr>
<td>(utf32-&gt;string bytevector endianness)</td>
<td>procedure</td>
<td>288</td>
</tr>
<tr>
<td>(utf32-&gt;string bytevector endianness-endianness-mandatory?)</td>
<td>procedure</td>
<td>288</td>
</tr>
<tr>
<td>(utf8-&gt;string bytevector)</td>
<td>procedure</td>
<td>287</td>
</tr>
<tr>
<td>(values obj ...)</td>
<td>procedure</td>
<td>131</td>
</tr>
<tr>
<td>variable</td>
<td>syntax</td>
<td>91</td>
</tr>
<tr>
<td>(vector obj ...)</td>
<td>procedure</td>
<td>224</td>
</tr>
<tr>
<td>(vector-&gt;immutable-vector vector)</td>
<td>procedure</td>
<td>155</td>
</tr>
<tr>
<td>(vector-&gt;list vector)</td>
<td>procedure</td>
<td>225</td>
</tr>
<tr>
<td>(vector-&gt;pseudo-random-generator vec)</td>
<td>procedure</td>
<td>234</td>
</tr>
</tbody>
</table>
Summary of Forms

**(vector->pseudo-random-generator! prgen vec)**  
procedure 234

**(vector-cas! vector n old-obj new-obj)**  
procedure 154

**(vector-copy vector)**  
procedure 153

**(vector-fill! vector obj)**  
procedure 225

**(vector-for-each procedure vector1 vector2 ...)**  
procedure 122

**(vector-length vector)**  
procedure 224

**(vector-map procedure vector1 vector2 ...)**  
procedure 121

**(vector-ref vector n)**  
procedure 224

**(vector-set! vector n obj)**  
procedure 225

**(vector-set-fixnum! vector n fixnum)**  
procedure 154

**(vector-sort predicate vector)**  
procedure 226

**(vector-sort! predicate vector)**  
procedure 226

**(vector? obj)**  
procedure 154

**(verify-loadability situation input ...)**  
procedure 367

**(vfasl-convert-file input-path output-path base-boots)**  
procedure 378

**(violation? obj)**  
procedure 366

**(virtual-register k)**  
procedure 432

**(virtual-register-count)**  
procedure 432

**(visit path)**  
procedure 368

**(visit-compiled-from-port input-port)**  
procedure 368

**(void)**  
procedure 175

**(waiter-prompt-and-read input-port)**  
thread param 409

**(waiter-prompt-string input-port)**  
thread param 408

**(waiter-write string)**  
thread param 409

**(warning who msg irritant ...)**  
procedure 353

**(warning? obj)**  
procedure 367

**(warningf who msg irritant ...)**  
procedure 354

**(weak-cons obj1 obj2)**  
procedure 443

**(weak-pair? obj)**  
procedure 444

**(when test-expr expr1 expr2 ...)**  
syntax 112

**(who-condition? obj)**  
procedure 369

**(with ((pat expr) ...) template)**  
syntax 485

**(with-continuation-mark key val body)**  
syntax 131

**(with-cost-center cost-center thunk)**  
procedure 428

**(with-cost-center timed? cost-center thunk)**  
procedure 428

**(with-exception-handler procedure thunk)**  
procedure 360

**(with-implicit (id0 id1 ...) body1 body2 ...)**  
syntax 325

**(with-input-from-file path thunk)**  
procedure 258

**(with-input-from-file path thunk options)**  
procedure 258

**(with-input-from-string string thunk)**  
procedure 254

**(with-interrupts-disabled body1 body2 ...)**  
syntax 360

**(with-mutex mutex body1 body2 ...)**  
syntax 470

**(with-output-to-file path thunk)**  
procedure 267

**(with-output-to-file path thunk options)**  
procedure 267

**(with-output-to-string thunk)**  
procedure 255

**(with-profile-tracker thunk)**  
procedure 403

**(with-profile-tracker preserve-existing? thunk)**  
procedure 403

**(with-source-path who name procedure)**  
procedure 388
Summary of Forms

<table>
<thead>
<tr>
<th>Expression</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(with-syntax ((pattern expr) ...) body₁ body₂ ...)</td>
<td>syntax 304</td>
</tr>
<tr>
<td>(wrapper-procedure-data w-proc)</td>
<td>procedure 210</td>
</tr>
<tr>
<td>(wrapper-procedure-procedure w-proc)</td>
<td>procedure 210</td>
</tr>
<tr>
<td>(wrapper-procedure? obj)</td>
<td>procedure 209</td>
</tr>
<tr>
<td>(write obj)</td>
<td>procedure 284</td>
</tr>
<tr>
<td>(write obj textual-output-port)</td>
<td>procedure 284</td>
</tr>
<tr>
<td>(write-char char)</td>
<td>procedure 285</td>
</tr>
<tr>
<td>(write-char char textual-output-port)</td>
<td>procedure 285</td>
</tr>
<tr>
<td>(zero? num)</td>
<td>procedure 173</td>
</tr>
</tbody>
</table>
Index

This index is a unified index for this book and *The Scheme Programming Language, 4th Edition* (TSPL4). Page numbers prefixed by “t” refer the latter document. Italicized page numbers refer to the primary description of a syntactic form or procedure.

! (exclamation point), t8
" (double quote), t216
#:res, t456
#:graph reference, 3 280
#:2% ($primitive), 390
#:3% ($primitive), 390
#: (primitive), 3 390
#: (box prefix), 3 168
#: (syntax), t300
#: (vector prefix), 3 153
#n (vector prefix), 3 153
#, (unsyntax), t305
#, (unsyntax-splicing), t305
#: (gensym prefix), 2 170 171 282
#: (datum comment), t455
#: (graph mark), 3 280
#: (record prefix), 3
#: , t211
#:alarm, 3
#:backspace, 3
#:bel, 3
#:delete, 3
#:esc, 3
#:linefeed, 3
#:ls, 3
#:nel, 3
#:newline, 3
#:nul, 3
#:page, 3
#:return, 3
#:rubout, 3
#: (gensym prefix), 2 170 171 282
#:space, 3
#:tab, 3
#:vt, 3
#: (quasisyntax), t305
#: (binary), t169
#: (decimal), t169
#: , t7
#:false, 4
#: (octal), t169
#: (radix prefix), 3
#:t, t7
#:true, 4
#:nfxl (flvector prefix), 158
#:nfx (fxvector prefix), 158
#:nfx (fxvector prefix), 155
#:nva (stencil vector prefix), 165
#:x (hexadecimal), t169
#:... (block comment), t455
$primitive ( #%), 390
$primitive ( #2%), 390
$primitive ( #3%), 390
$system, 339
$system module, 339
(assertion, t366
&assertion, t366
&condition, t362
&continuation, 335
&error, t367
&format, 334
&a/o, t371
&a/o-decoding, t375
&a/o-encoding, t376
&a/o-file-already-exists, t374
&a/o-file-does-not-exist, t374
&a/o-file-is-read-only, t374
&a/o-file-protection, t373
&a/o-file-name, t373
&a/o-invalid-position, t372
&a/o-port, t375
&a/o-read, t372
&a/o-write, t372
&implementation-restriction, t369
&irritants, t368
&lexical, t370
&message, t368
&no-infinities, t376
&no-nans, t377
&non-continuable, t369
&serious, t366
&source, 334
&syntax, t370
&undefined, t371
&violation, t366
&warning, t367
&who, t369
' (quote), t17, t141
atom?, t41
auxiliary keywords, t41

base case, t41
base-exception-handler, t41
begin, t41
begin, t41
bignum, t41
bignum?, t41
binary port, t41
binary trees, t41
binary-port-input-buffer, t41
binary-port-input-count, t41
binary-port-input-index, t41
binary-port-input-size, t41
binary-port-output-buffer, t41
binary-port-output-count, t41
binary-port-output-index, t41
binary-port-output-size, t41
binary-port?, t41
binding, t41
bitwise-and, t41
bitwise-arithmetic-shift, t41
bitwise-arithmetic-shift-left, t41
bitwise-arithmetic-shift-right, t41
bitwise-bit-count, t41
bitwise-bit-field, t41
bitwise-bit-set?, t41
bitwise-copy-bit, t41
bitwise-copy-bit-field, t41
bitwise-first-bit-set, t41
bitwise-if, t41
bitwise-ior, t41
bitwise-length, t41
bitwise-not, t41
bitwise-reverse-bit-field, t41
bitwise-rotate-bit-field, t41
bitwise-xor, t41
block buffering, t41
block comment ( #|...|# ), t41
block profiling, t41
block structure, t41
block-read, t41
block-write, t41
boolean, t41
boolean syntax, t41
boolean values, t41
boolean=?, t41
boot files, t41
bound-identifier=?, t41
box, t41
box-cas!, t41
box-immobile, t41
box-immutable, t41
box?, t41
boxes, t41
brackets ( [ ] ), t41
break, t41
break-handler, t41
broadcast streams, t41
buffer modes, t41
buffer-mode, t41
buffer-mode?, t41
bw-obj?, t41
bytes-allocated, t41
bytes-deallocated, t41
bytes-finalized, t41
bytevector, t41
bytevector syntax, t41
bytevector->immutable-bytevector, t41
bytevector->s8-list, t41
bytevector->sint-list, t41
bytevector->string, t41
bytevector->u8-list, t41
bytevector->u16-list, t41
bytevector->u32-list, t41
bytevector-compress, t41
bytevector-copy, t41
bytevector-copy!, t41
bytevector-fill!, t41
bytevector-ieee-double-native-ref, t41
bytevector-ieee-double-native-set!, t41
bytevector-ieee-double-ref, t41
bytevector-ieee-double-set!, t41
bytevector-ieee-double-native-ref, t41
bytevector-ieee-double-native-set!, t41
bytevector-ieee-single-native-ref, t41
bytevector-ieee-single-native-set!, t41
bytevector-ieee-single-native-ref, t41
bytevector-ieee-single-native-set!, t41
bytevector-length, t41
bytevector-reference-ref, t41
bytevector-reference-set!, t41
bytevector-s16-native-ref, t41
bytevector-s16-native-set!, t41
bytevector-s16-ref, t41
bytevector-s16-set!, t41
bytevector-s24-ref, t41
bytevector-s24-set!, t41
bytevector-s32-native-ref, t41
bytevector-s32-native-set!, t41
bytevector-s32-ref, t41
bytevector-s32-set!, t41
bytevector-s40-ref, t41
bytevector-s40-set!, t41
bytevector-s48-ref, t41
bytevector-s48-set!, t41
bytevector-s56-ref, t41
bytevector-s56-set!, t41
bytevector-s64-native-ref, t41
bytevector-s64-native-set!, t41
bytevector-s64-ref, t41
bytevector-s64-set!, t41
bytevector-s8-ref, t41
bytevector-s8-set!, t41
bytevector-sint-ref, t41
bytevector-sint-set!, t41
bytevector-truncate!, 162
bytevector-u16-native-ref, t232
bytevector-u16-native-set!, t233
bytevector-u16-ref, t235
bytevector-u16-set!, t236
bytevector-u24-ref, 165
bytevector-u24-set!, t233
bytevector-u32-native-ref, t232
bytevector-u32-native-set!, t233
bytevector-u32-ref, t235
bytevector-u32-set!, t236
bytevector-u8-ref, 165
bytevector-u8-set!, t233
bytevector-u8-truncate!, 162
bytevector-u8-native-ref, t232
bytevector-u8-native-set!, t233
bytevector-u8-ref, t235
bytevector-u8-set!, t236
bytevector-u8-uncompress, 164
bytevector-, t229
bytevector?, t155

C, t393
C (programming language), 57, 59, 95, 97
C preprocessor macros, 97
C-callable library functions, 97
caaaar, t157
caad, t157
caaar, t157
caaddr, t157
caddr, t157
cadr, t157
cadr, t157
carer, t155
caadr, ..., cddddr, t34
caddar, t157
caddr, t157
cdar, t157
cddar, t157
cdddr, t157
cdddr, t157
cdddr, t157
cddr, t157
cddr, t34, t157
cdr, t38, t156
cstuff, t177
cfl-, 225
cfl+, 225
cfl-, 225
cfl conjugate, 225
cfl imag part, 222
cfl magnitude-squared, 224
cfl real part, 222
cfl, 225
cfl, 225
cflonum, 214
cflonum?, 215
cflonums, 222
cchar, 93, 94
char-, 148
char->integer, t215
char-alphabetic?, t213
char-ci<=?, t212, 148
char-ci<, t212, 148
char-ci=, t212, 148
char-ci>, t212, 148
char-ci? , t212, 148
char-downcase, t214
char-extended-pictographic?, t215
char-foldcase, t215
char-general-category, t214
char-grapheme-break-property, 149
char-grapheme-step, 149
char-lower-case?, t213
char-name, 148, 278
char-numeric?, t213
char-ready?, 263
char-title-case?, t213

call-with-port, t272
call-with-string-output-port, t266
call-with-values, t130, t131
call/cc, t125, t123
car, t155, t156
case, t306, t113, 127
case-lambda, t94, t94, 149
case-sensitive, 279
cd, 280
cdaar, t157
cdaadr, t157
cdaar, t157
cdad, t157
cdaddr, t157
cdadr, t157
cdadr, t157

call-with-bytevector-output-port, t266
call-with-current-continuation, t426, t123
call-with-immediate-continuation-mark, 135
call-with-input-file, t281, 258
call-with-output-file, t282, 258

call-with-bytevector-output-port, t266
call-with-current-continuation, t426, t123
call-with-immediate-continuation-mark, 135
call-with-input-file, t281, 258
call-with-output-file, t282, 258

call-with-bytevector-output-port, t266
call-with-current-continuation, t426, t123
call-with-immediate-continuation-mark, 135
call-with-input-file, t281, 258
call-with-output-file, t282, 258

call-with-bytevector-output-port, t266
call-with-current-continuation, t426, t123
call-with-immediate-continuation-mark, 135
call-with-input-file, t281, 258
call-with-output-file, t282, 258

call-with-bytevector-output-port, t266
call-with-current-continuation, t426, t123
call-with-immediate-continuation-mark, 135
call-with-input-file, t281, 258
call-with-output-file, t282, 258

call-with-bytevector-output-port, t266
call-with-current-continuation, t426, t123
call-with-immediate-continuation-mark, 135
call-with-input-file, t281, 258
call-with-output-file, t282, 258

C, t393
C (programming language), 57, 59, 95, 97
C preprocessor macros, 97
C-callable library functions, 97
caaaar, t157
caad, t157
caaar, t157
caaddr, t157
caddr, t157
cadr, t157
cadr, t157
carer, t155
caadr, ..., cddddr, t34
caddar, t157
caddr, t157
cdar, t157
cddar, t157
cdddr, t157
cdddr, t157
cdddr, t157
cddr, t157
cddr, t34, t157
cdr, t38, t156
cstuff, t177
cfl-, 225
cfl+, 225
cfl-, 225
cfl conjugate, 225
cfl imag part, 222
cfl magnitude-squared, 224
cfl real part, 222
cfl, 225
cfl, 225
cflonum, 214
cflonum?, 215
cflonums, 222
cchar, 93, 94
char-, 148
char->integer, t215
char-alphabetic?, t213
char-ci<=?, t212, 148
char-ci<, t212, 148
char-ci=, t212, 148
char-ci>, t212, 148
char-downcase, t214
char-extended-pictographic?, t215
char-foldcase, t215
char-general-category, t214
char-grapheme-break-property, 149
char-grapheme-step, 149
char-lower-case?, t213
char-name, 148, 278
char-numeric?, t213
char-ready?, 263
char-title-case?, t213
Index

char-titlecase, t214
char-upcase, t214
char-upper-case?, t213
char-whitespace?, t213
char<=?, t212, 148
char<, t212, 148
char?, t212, 148
char->?, t212, 148
char>=?, t212, 148
char?, t154
character syntax, t457
characters, t211
Chez Scheme, tix
CHEZSCHEMELIBDIRS, 22
CHEZSCHEMELIBEXTS, 22
child type, t325
cmd, 257
circular lists, t156
clear-input-port, 242
clear-output-port, 253
close-input-port, t285
close-output-port, t285
close-port, t270
codec, t257
collect, 438, 440
collect-generation-radix, 438, 440
collect-maximum-generation, 437, 441
collect-maximum-generation-threshold-factor, 438, 440
collect-notify, 440
collect-rendezvous, 440
collect-request-handler, 437, 440, 450
collections, 423
command-line, t350, 411, 412
command-line options, 30
command-line-arguments, 411, 412
comments, t455
Common Lisp, t6
commonization-level, 395
compilation, 369
compile, 363, 365, 391
compile-file, 10, 261, 369, 389
compile-file-message, 395
compile-imported-libraries, 18, 19, 316
compile-interp-simple, 391
compile-library, 19, 23, 26, 367, 372
compile-library-handler, 372
compile-omit-concatenate-support, 388
compile-port, 374
compile-procedure-realm, 378
compile-profile, 398, 401
compile-program, 19, 20, 23, 26, 306, 367, 372
compile-program-handler, 372
compile-script, 21, 26, 370
compile-time-value, 330
compile-time-value?, 330
compile-to-file, 372, 376
compile-to-port, 376
compile-whole-library, 397, 398
compile-whole-program, 28, 307, 375, 392
compiler, t4
compiled, see engines, see engines
complex numbers, t167, 222
complex?, t167, t151
compose, t34
compound condition, t362
compress-format, 164, 242, 253, 266, 288
compress-level, 164, 242, 253, 266, 288
compute-composition, 475
compute-size, 22, 24
compute-size-increments, 30
concatenate-object-files, 346
concatenated streams, 259
cond, t44, t111, 484
condition, t362
condition object, t361
condition type, t361
collection-accessor, t365
collection-broadcast, 473
collection-continuation, 455
collection-irritants, t368
collection-message, 368
collection-name, 471
collection-predicate, t365
collection-signal, 471
condition-wait, 470
condition-who, t369
condition?, t362
condition?, t362
conditionals, t109
conditions, t357
conjugate, 223, 257
cos, t19, t156
cos cell, t155
cos*, t158
cosing, t19
coroutine error-port, 205
coroutine-input-port, 206, 408
coroutine-output-port, 204, 408
constant, t141
constants, t141
constructor, t199
core syntactic forms, t4
cos, t185
<table>
<thead>
<tr>
<th>Index</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>dx/y, t131</td>
<td>545</td>
</tr>
<tr>
<td>dynamic allocation, t3</td>
<td>545</td>
</tr>
<tr>
<td>dynamic-wind, t124</td>
<td>545</td>
</tr>
<tr>
<td>echo streams, 239</td>
<td>545</td>
</tr>
<tr>
<td>ee-accept, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-auto-indent, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-auto-paren-balance, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-backward-char, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-backward-delete-char, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-backward-delete-sexp, 461</td>
<td>545</td>
</tr>
<tr>
<td>ee-backward-page, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-backward-sexp, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-backward-word, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-beginning-of-entry, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-beginning-of-line, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-bind-key, 457</td>
<td>545</td>
</tr>
<tr>
<td>ee-command-repeat, 464</td>
<td>545</td>
</tr>
<tr>
<td>ee-common-identifiers, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-compose, 457</td>
<td>545</td>
</tr>
<tr>
<td>ee-default-repeat, 456</td>
<td>545</td>
</tr>
<tr>
<td>ee-delete-between-point-and-mark, 461</td>
<td>545</td>
</tr>
<tr>
<td>ee-delete-char, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-delete-entry, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-delete-line, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-delete-sexp, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-delete-to-eol, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-end-of-entry, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-end-of-line, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-eof, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-eof/delete-char, 464</td>
<td>545</td>
</tr>
<tr>
<td>ee-exchange-point-and-mark, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-flash-matching-delimiter, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-flash-parens, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-forward-char, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-forward-page, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-forward-sexp, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-forward-word, 460</td>
<td>545</td>
</tr>
<tr>
<td>ee-goto-matching-delimiter, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-bwd, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-bwd-contains, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-bwd-prefix, 462</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-fw, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-fw-contains, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-fwd-prefix, 462</td>
<td>545</td>
</tr>
<tr>
<td>ee-history-limit, 456</td>
<td>545</td>
</tr>
<tr>
<td>ee-id-completion, 461</td>
<td>545</td>
</tr>
<tr>
<td>ee-id-completion/indent, 461</td>
<td>545</td>
</tr>
<tr>
<td>ee-indent, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-indent-all, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-insert-paren, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-insert-self, 457</td>
<td>545</td>
</tr>
<tr>
<td>ee-newline, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-newline/accept, 464</td>
<td>545</td>
</tr>
<tr>
<td>ee-next-id-completion, 462</td>
<td>545</td>
</tr>
<tr>
<td>ee-next-id-completion/indent, 462</td>
<td>545</td>
</tr>
<tr>
<td>ee-next-line, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-noisy, 456</td>
<td>545</td>
</tr>
<tr>
<td>ee-open-line, 458</td>
<td>545</td>
</tr>
<tr>
<td>ee-paren-flash-delay, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-paren-kill-buffer, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-previous-line, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-redisplay, 463</td>
<td>545</td>
</tr>
<tr>
<td>ee-reset-entry, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-set-mark, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-standard-indent, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-string-macro, 459</td>
<td>545</td>
</tr>
<tr>
<td>ee-suspend-process, 459</td>
<td>545</td>
</tr>
<tr>
<td>else, t113, t112</td>
<td>545</td>
</tr>
<tr>
<td>else, t113</td>
<td>545</td>
</tr>
<tr>
<td>empty list, t19</td>
<td>545</td>
</tr>
<tr>
<td>enable-arithmetic-left-associative, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-cross-library-optimization, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-error-source-expression, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-interrupts, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-object-backreferences, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-object-counts, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-type-recovery, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-unsafe-application, 459</td>
<td>545</td>
</tr>
<tr>
<td>enable-unsafe-variable-reference, 459</td>
<td>545</td>
</tr>
<tr>
<td>endianness, t259</td>
<td>545</td>
</tr>
<tr>
<td>engine-block, 144</td>
<td>545</td>
</tr>
<tr>
<td>engine-return, 144</td>
<td>545</td>
</tr>
<tr>
<td>engines, t421</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-&gt;list, 1252</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-complement, 1254</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-constructor, 1251</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-difference, 1253</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-indexer, 1254</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-intersection, 1253</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-member?, 1253</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-projection, 1254</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-subset?, 1252</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-union, 1253</td>
<td>545</td>
</tr>
<tr>
<td>enum-set-universe, 1252</td>
<td>545</td>
</tr>
<tr>
<td>enum-set?, 1252</td>
<td>545</td>
</tr>
<tr>
<td>enumerate, 144</td>
<td>545</td>
</tr>
<tr>
<td>environment, t404</td>
<td>545</td>
</tr>
<tr>
<td>environment, t137</td>
<td>545</td>
</tr>
<tr>
<td>environment-mutable?, 367</td>
<td>545</td>
</tr>
<tr>
<td>environment-symbols, 363</td>
<td>545</td>
</tr>
<tr>
<td>environment?, 367</td>
<td>545</td>
</tr>
<tr>
<td>eof object, t257</td>
<td>545</td>
</tr>
<tr>
<td>eof-object, t273</td>
<td>545</td>
</tr>
<tr>
<td>eof-object?, t257, t273</td>
<td>545</td>
</tr>
<tr>
<td>col style, t257</td>
<td>545</td>
</tr>
<tr>
<td>col-style, t259</td>
<td>545</td>
</tr>
<tr>
<td>ephemeron pairs, 443</td>
<td>545</td>
</tr>
<tr>
<td>ephemeron-cons, 444</td>
<td>545</td>
</tr>
<tr>
<td>ephemeron-pair?, 445</td>
<td>545</td>
</tr>
<tr>
<td>eq-hashtable-cell, 183</td>
<td>545</td>
</tr>
<tr>
<td>eq-hashtable-contains?, 182</td>
<td>545</td>
</tr>
<tr>
<td>eq-hashtable-delete!, 182</td>
<td>545</td>
</tr>
</tbody>
</table>
eq-hash-table-ephemeron?, 181
eq-hash-table-ref, 181
eq-hash-table-ref-cell, 183
eq-hash-table-set!, 181
eq-hash-table-try-atomic-cell, 183
eq-hash-table-update!, 182
eq-hash-table-weak?, 181
eq-hash-table?, 181
eq?, t143
equal-hash, t245, 188
equal-hash on records, 188
equal?, t148, 188
equal? on records, 188
 equivalence predicates, t143
eqv?, t38, t146
error, t358
 error handling mode, t258
error-handling-mode, t260
error?, t367
errorf, 354
 except import set, t346
 except import set, t346
 exception handling, 353
except, 358
 exceptions, t357
exclamation point ( ! ), t8
exclusive-cond, t124
exists, t119
exit, t350, t116
exit-handler, t116
exp, t184
expand, 379, 390, 396, 408
expand-omit-library-invocations, 387
expand-output, 379, 396
expand-time generativity, 193
expand/optimize, 387, 394, 396
expand/optimize-output, 380, 396
expansion, t59
expire, see engines, see engines
export, t345, 372
export level, t345
expression-editor, t55
expressions, t7
exp, t179
expt-mod, 236
extend-syntax, 483
extended examples, t381
f (single), t169
factor, t71
factorial, t75
false, t36
fasl-compressed, 286
fasl-file, 286
fasl-read, 284
fasl-strip-options, 277
fasl-write, 286
fast Fourier transform (FFT), t412
fast loading format, 286
fenders, t301, 483, 485
fibonacci, t102, t137
Fibonacci numbers, t102
fields, t331
file, t257
file-access-time, 200
file-buffer-size, 200
file-change-time, 200
file-directory?, t286, t289
file-exists?, t286, t289
file-length, 250
file-modification-time, 290
file-options, t261
file-port?, 256
file-position, 256
file-regular?, 256
file-symbolic-link?, 256
filter, t164
find, t165
finite?, t174
first-class data values, t3
first-class procedures, t5
fixnum, t192, 213, 214
fixnum, 63
fixnum->flonum, 211
fixnum-width, t193
fixnum?, t193
fl+, 206
fl-<, 220
fl-=, 220
fl=, 220
fl>=, 220
fl=>, 220
fl=, 220
fl>?, 220
fl<?, 220
fl<=?, 220
fl?=, 220
fl<=>, 220
fl<=>?, 220
flabs, 209
flacos, 210
flasin, 210
flatan, 210
flceiling, 208
Index

flcos, t210
fldenominator, t209
fldiv, t207
fldiv-and-mod, t207
fldiv0, t208
fldiv0-and-mod0, t208
fleven?, t205
flexp, t209
flfinite?, t205
flfloor, t208
flinfinite?, t205
flinteger?, t204
flip-flop, t102
fllog, t209
flmax, t205
flmin, t205
fmod, t207
flmod, t207
flmod0, t208
flnan?, t205
flnegative?, t204
flnonnegative?, t203
flonum, t202, 213, 214
flonum->fixnum, t219
flonum?, t203
floor, t177
flpositive?, t204
flround, t208
fisn, t210
fisingle, t221
fsqrt, t210
ftan, t210
fitruncate, t208
flvector, t158
flvector->list, t160
flvector-copy, t160
flvector-fill!, t160
flvector-length, t159
flvector-ref, t159
flvector-set!, t159
flvector?, t158
flvectors, t158
fizer?, t204
fold-left, t120
fold-right, t121
folding, t121
for-all, t119
for-each, t118
force, t128
foreign entry, 59
foreign types, 72
foreign-address-name, 74
foreign-alignof, 77
foreign-alloc, 77
foreign-callable, 76
foreign-callable-code-object, 73
foreign-callable-entry-point, 71, 73
foreign-entry, 95
foreign-entry?, 95
foreign-free, 73
foreign-procedure, t26
foreign-procedure interface, 59
foreign-ref, 76
foreign-set!, 77
foreign-sizeof, 77
fork-thread, t26
formal parameters, t26
format, t272, 287
format-condition?, 354
formatted error messages, 354
formatted output, t401, 276
fprintf, t401, 277
Fred, t174
free variable, t28
free-identifier=?, 17, t302
frequency, t393
fresh-line, t370
ftype, 54, 58
ftype subtyping, 82
ftype=ref, 53
ftype-guardian, t360, 361, 473, 474
ftype-init-lock!, 472
ftype-lock!, 473
ftype-locked-decr!, 476
ftype-locked-incr!, 476
ftype-pointer->sexpr, 89
ftype-pointer-address, 84
ftype-pointer-ftype, 88
ftype-pointer-null?, 85
ftype-pointer=?, 85
ftype-pointer?, 86
ftype-pointer-address, 85
ftype-pointer-ftype, 88
ftype-pointer-null?, 85
ftype-pointer=?, 85
ftype-pointer?, 86
ftype-ref, 86
ftype-set!, 86
ftype-sizeof, 82
ftype-spin-lock!, 472
ftype-unlock!, 472
ftypes, 77
function ftype, 78, 83, 84
fx*, t195, 217
fx*+carry, t197
fx*+wraparound, 218
fx+, t195, 216
fx+carry, t197
fx+wraparound, 218
fx-, t195, 217
fx-+carry, t197
Index

get-string-n!, t276
get-string-some, 259
get-string-some!, 259
get-string-some!, t276
get-thread-id, t276
goodbye, t41
greatest-fixnum, t193
guard, t361
guardian?, t361, 450, 474
guardians, 443
half, 33
hare and tortoise, t66
hash-table-for-each, t246
hash-table-map, t246
hash-table?, t246
hashable, t246
hashable-clear!, t246
hashable-contains?, t246
hashable-copy, t246
hashable-delete!, t246
hashable-entries, t250, t250
hashable-ephemeront, t249
hashable-equivalence-function, t249
hashable-hash-function, t249
hashable-keys, t249, t249
hashable-mutable?, t249
hashable-ref, t249
hashable-ref-cell, t249
hashable-set!, t249
hashable-size, t249
hashable-update!, t249
hashable-values, t249
hashable-weak?, t249
hashable?, t155
hashtables, t243
heap files, 51
heap-reserve-ratio, 442
i/o-decoding-error?, t375
i/o-encoding-error-char, t375
i/o-encoding-error?, t375
i/o-error-filename, t375
i/o-error-port, t375
i/o-error-pos, t375
i/o-error-pos, t375
i/o-file-already-exists-error?, t374
i/o-file-does-not-exist-error?, t374
i/o-file-is-read-only-error?, t374
i/o-file-protection-error?, t373
i/o-filename-error?, t373
i/o-invalid-position-error?, t372
i/o-port-error?, t372
i/o-read-error?, t372
i/o-write-error?, t372
iconv-codec, t244, t244
identifier-syntax, t291, t291
identifier?, t301
identifiers, t6
ieee, 339
ieee module, t339
ieee-environment, t339, 339
if, t39, t109
imag-part, t182
imaginary numbers, 222
immutability of exports, t349
immutable, 199
immutable, t331
immutable boxes, 168, 170
immutable bytevectors, 161, 164
immutable strings, 160, 162
immutable vectors, 153, 155
immutable-box?, t159
immutable-bytevector?, t164
immutable-string?, t152
immutable-vector?, t152
implementation-restriction-violation?, t369
implicit begin, t109
implicit-exports, t374
import, t345, t117, t117, t308, 310
import level, t345
import spec, t346
import-notify, t18, 317
import-only, t117, 308
improper list, t155
in-place-minimum-generation, 442
include, t309, t309, t326
indirect exports, t349
indirect-export, t379
inexact, t180
inexact complexnum, 213
inexact->exact, t181
inexact?, t167, t170
infinite?, t174
inheritance, t412
inheritance in records, t325, 193, 196
initial-bytes-allocated, t109
INITLOCK, t109
inlining, 22
input port, t257
input-port-ready?, t58, 203
input-port?, t270
inspect, 42
inspect/object, t42
inspector, t41
int, 62, 66
integer-16, 61, 65
integer-32, 61, 65
integer-64, 61, 65
integer-8, 61, 65
integer->char, t215
integer->divide, t79
<table>
<thead>
<tr>
<th>Term</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>integer-length</td>
<td>296</td>
</tr>
<tr>
<td>integer-valued?</td>
<td>1153</td>
</tr>
<tr>
<td>integer?</td>
<td>t167</td>
</tr>
<tr>
<td>integers</td>
<td>t167</td>
</tr>
<tr>
<td>integrable procedures</td>
<td>t315</td>
</tr>
<tr>
<td>interaction environment</td>
<td>14</td>
</tr>
<tr>
<td>interaction-environment</td>
<td>15</td>
</tr>
<tr>
<td>interaction top level</td>
<td>14</td>
</tr>
<tr>
<td>interactive?</td>
<td>433</td>
</tr>
<tr>
<td>internal definitions</td>
<td>t92</td>
</tr>
<tr>
<td>internal state</td>
<td>t49</td>
</tr>
<tr>
<td>internal-defines-as-letrec*</td>
<td>118</td>
</tr>
<tr>
<td>interpret</td>
<td>t404</td>
</tr>
<tr>
<td>interpreter</td>
<td>t404</td>
</tr>
<tr>
<td>interrupts</td>
<td>354</td>
</tr>
<tr>
<td>intraline whitespace</td>
<td>t455</td>
</tr>
<tr>
<td>invoke-library</td>
<td>315</td>
</tr>
<tr>
<td>iota</td>
<td>145</td>
</tr>
<tr>
<td>iptr</td>
<td>62, 66</td>
</tr>
<tr>
<td>irritants-condition?</td>
<td>t368</td>
</tr>
<tr>
<td>isqrt</td>
<td>236</td>
</tr>
<tr>
<td>iteration</td>
<td>t121</td>
</tr>
<tr>
<td>keep-live</td>
<td>442</td>
</tr>
<tr>
<td>kernel</td>
<td>23</td>
</tr>
<tr>
<td>keyboard-interrupt-handler</td>
<td>356</td>
</tr>
<tr>
<td>keyword definition</td>
<td>t117</td>
</tr>
<tr>
<td>keywords</td>
<td>t61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Term</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (long)</td>
<td>t169</td>
</tr>
<tr>
<td>lambda</td>
<td>t33</td>
</tr>
<tr>
<td>lambdas</td>
<td>t94</td>
</tr>
<tr>
<td>last-pair</td>
<td>t44</td>
</tr>
<tr>
<td>latin-1</td>
<td>t257</td>
</tr>
<tr>
<td>latin-1-codec</td>
<td>t259</td>
</tr>
<tr>
<td>lazy</td>
<td>t51</td>
</tr>
<tr>
<td>lazy evaluation</td>
<td>t51</td>
</tr>
<tr>
<td>lcm</td>
<td>t179</td>
</tr>
<tr>
<td>least-fixnum</td>
<td>t193</td>
</tr>
<tr>
<td>length</td>
<td>t42, t159</td>
</tr>
<tr>
<td>let,</td>
<td>t34</td>
</tr>
<tr>
<td>let*</td>
<td>t64, t96, 484</td>
</tr>
<tr>
<td>let**-values</td>
<td>t134, t99</td>
</tr>
<tr>
<td>let-bound variables</td>
<td>t23</td>
</tr>
<tr>
<td>let-syntx</td>
<td>t314, t293, 117</td>
</tr>
<tr>
<td>let-values</td>
<td>t134, t99</td>
</tr>
<tr>
<td>letrec</td>
<td>t310, t97</td>
</tr>
<tr>
<td>letrec*</td>
<td>t98</td>
</tr>
<tr>
<td>letrec-syntax</td>
<td>t314, t293, 117</td>
</tr>
<tr>
<td>lexical scoping</td>
<td>t63</td>
</tr>
<tr>
<td>libraries</td>
<td>17, 23 t343, 303</td>
</tr>
<tr>
<td>library</td>
<td>306</td>
</tr>
<tr>
<td>library body</td>
<td>t348</td>
</tr>
<tr>
<td>library version</td>
<td>t344</td>
</tr>
<tr>
<td>library version reference</td>
<td>t347</td>
</tr>
<tr>
<td>library-directories</td>
<td>t18</td>
</tr>
<tr>
<td>library-exports</td>
<td>318</td>
</tr>
<tr>
<td>library-extensions</td>
<td>15</td>
</tr>
<tr>
<td>library-list</td>
<td>318</td>
</tr>
<tr>
<td>library-object-filename</td>
<td>20</td>
</tr>
<tr>
<td>library-requirements</td>
<td>20</td>
</tr>
<tr>
<td>library-requirements-options</td>
<td>319</td>
</tr>
<tr>
<td>library-search-handler</td>
<td>317</td>
</tr>
<tr>
<td>library-timestamp-mode</td>
<td>317</td>
</tr>
<tr>
<td>library-version</td>
<td>318</td>
</tr>
<tr>
<td>light-weight threads</td>
<td>t421</td>
</tr>
<tr>
<td>line buffering</td>
<td>t258</td>
</tr>
<tr>
<td>line ending</td>
<td>t455</td>
</tr>
<tr>
<td>Lisp</td>
<td>t6</td>
</tr>
<tr>
<td>lisp-cdr</td>
<td>t38</td>
</tr>
<tr>
<td>list</td>
<td>t20, t158</td>
</tr>
<tr>
<td>list constants</td>
<td>t7</td>
</tr>
<tr>
<td>list syntax</td>
<td>t460</td>
</tr>
<tr>
<td>list*</td>
<td>149</td>
</tr>
<tr>
<td>list-&gt;fvector</td>
<td>160</td>
</tr>
<tr>
<td>list-&gt;fxvector</td>
<td>154</td>
</tr>
<tr>
<td>list-&gt;string</td>
<td>t223</td>
</tr>
<tr>
<td>list-&gt;vector</td>
<td>t226</td>
</tr>
<tr>
<td>list-assuming-immutable?</td>
<td>t444</td>
</tr>
<tr>
<td>list-copy</td>
<td>t43, 149</td>
</tr>
<tr>
<td>list-head</td>
<td>144</td>
</tr>
<tr>
<td>list-ref</td>
<td>t159</td>
</tr>
<tr>
<td>list-sort</td>
<td>t387, t167</td>
</tr>
<tr>
<td>list-tail</td>
<td>t160</td>
</tr>
<tr>
<td>list?</td>
<td>t67, t158</td>
</tr>
<tr>
<td>lists</td>
<td>t155</td>
</tr>
<tr>
<td>literal-identifier=?</td>
<td>325</td>
</tr>
<tr>
<td>literals</td>
<td>t294, 329</td>
</tr>
<tr>
<td>load</td>
<td>t13, 117, 368, 370</td>
</tr>
<tr>
<td>load-compiled-from-port</td>
<td>368</td>
</tr>
<tr>
<td>load-library</td>
<td>306</td>
</tr>
<tr>
<td>load-program</td>
<td>309</td>
</tr>
<tr>
<td>load-shared-object</td>
<td>95</td>
</tr>
<tr>
<td>local variable bindings</td>
<td>t95</td>
</tr>
<tr>
<td>locate-source</td>
<td>143</td>
</tr>
<tr>
<td>locate-source-object-source</td>
<td>343</td>
</tr>
<tr>
<td>lock-object</td>
<td>t114, t357</td>
</tr>
<tr>
<td>locked-object?</td>
<td>t52</td>
</tr>
<tr>
<td>LOCKED_DEC</td>
<td>109</td>
</tr>
<tr>
<td>LOCATED_INCR</td>
<td>109, 174</td>
</tr>
<tr>
<td>locks</td>
<td>171</td>
</tr>
<tr>
<td>log,</td>
<td>t184</td>
</tr>
<tr>
<td>logand</td>
<td>224</td>
</tr>
<tr>
<td>logbit0</td>
<td>227</td>
</tr>
<tr>
<td>logbit1</td>
<td>228</td>
</tr>
<tr>
<td>logbit?</td>
<td>226</td>
</tr>
<tr>
<td>logior</td>
<td>229</td>
</tr>
<tr>
<td>lognot</td>
<td>226</td>
</tr>
<tr>
<td>logor</td>
<td>225</td>
</tr>
<tr>
<td>logtest</td>
<td>227</td>
</tr>
<tr>
<td>logzor</td>
<td>225</td>
</tr>
<tr>
<td>long</td>
<td>62, 66</td>
</tr>
<tr>
<td>long-long</td>
<td>62, 66</td>
</tr>
<tr>
<td>lookahead-char</td>
<td>t275</td>
</tr>
<tr>
<td>lookahead-u8</td>
<td>t274</td>
</tr>
</tbody>
</table>
Index

loop, t308
looping, t5

machine-type, 378
macros, t291
magnitude, t178, t183, 223
magnitude-squared, 224, 237
main.c, 24
make-annotation, 343, 345
make-arity-wrapper-procedure, 207
make-assertion-violation, t366
make-boot-file, 20, 376
make-boot-header, 377
make-byte-vector, 1238
make-codec-buffer, 247
make-compile-time-value, 328
make-condition, 170
make-continuation-condition, 355
make-cost-center, 126
make-counter, t54
make-custom-binary-input-port, t267
make-custom-binary-input-output-port, t267
make-custom-binary-output-port, t267
make-custom-textual-input-port, t268
make-custom-textual-input/output-port, t268
make-custom-textual-output-port, t268
make-date, 277
make-engine, 136
make-enumeration, t251
make-ephemeron-eq-hash-table, 180
make-ephemeron-eqv-hash-table, 180
make-ephemeron-hash-table, 180
make-ephemeron-extends-closure, 180
make-eq-hash-table, 243
make-eqv-hash-table, 234
make-error, 1367
make-fvector, 159
make-format-condition, 354
make-f-type-pointer, 82
make-fvector, 156
make-guardian, 446, 470
make-hash-table, 481
make-hashable, 234
make-i/o-decoding-error, t375
make-i/o-encoding-error, t376
make-i/o-error, t371
make-i/o-file-already-exists-error, t374
make-i/o-file-does-not-exist-error, t374
make-i/o-file-is-read-only-error, t374
make-i/o-file-protection-error, t373
make-i/o-filename-error, t373
make-i/o-invalid-position-error, t372
make-i/o-port-error, t375
make-i/o-read-error, t372
make-i/o-write-error, t372
make-immobile-byte-vector, 492
make-immobile-reference-byte-vector, 91
make-immobile-vector, 452
make-implementation-restriction-violation, t369
make-input-port, 242
make-input/output-port, 242
make-irritants-condition, t368
make-lexical-violation, t370
make-list, t94, 149
make-message-condition, t368
make-mutex, 469
make-no-infinities-violation, t376
make-no-nans-violation, t377
make-no-continuable-violation, t369
make-object-finder, 42, 158
make-output-port, 249
make-parameter, 429
make-pare, 183
make-phantom-byte-vector, 443
make-polar, t183
make-promise, t129
make-pseudo-random-generator, 239
make-queue, t54
make-record-constructor-descriptor, t332
make-record-type, t332, 207
make-record-type-descriptor, t323, t331, 208
make-rectangular, t182
make-reference-byte-vector, 91
make-serious-condition, t366
make-source-condition, 354
make-source-file-descriptor, 244, 247
make-source-object, 44, 346
make-source-table, 344
make-stack, 155
make-string, t218
make-syntax-violation, t370
make-thread-parameter, 376
make-time, 147
make-transcoder, t259
make-undefined-violation, t371
make-variable-transformer, t291, t306
make-vector, t224
make-violation, t366
make-warning, t367
make-weak-eq-hash-table, 179
make-weak-eqv-hash-table, 179
make-weak-hash-table, 179
make-who-condition, t369
make-who-configuration-violation, t369
make-wrapper-procedure, 207
map, t392, t117
map!, t46
mapping, t118
mark-port-closed, 247
matrix multiplication, t381
max, t178
maximum-memory-bytes, 425
maybe-compile-file, 372
maybe-compile-library, 372
maybe-compile-program, 372
member, t161
memory-order_acquire, 476
memory-order-release, 476
mem, t163
memq, t161
menv, t43, t161
merge, t387, 476
merge!, t387, 476
message-condition?, t368
messages, t408
meta, 117, 240
meta-circular interpreter, t404
meta-cond, 341
method, t317
min, t178
mkdir, 290
mod, t175
module, 117, 333
modules, 117, 333
modulo, t175
most-negative-fixnum, 215
most-positive-fixnum, 215
mul, t382
multibyte->string, 271
multiple values, t9
multiprocessing, t421, 135
mutable, 199
mutable boxes, 168, 170
mutable bytevectors, 164, 164
mutable strings, 150, 152
mutable vectors, 150, 152
mutable-box?, 169
mutable-bytevector?, 164
mutable-vector?, 152
mutex-acquire, 469
mutex-name, 469
mutex-release, 469
mutually recursive procedures, t97
mvlet, 381

named let, t67
naming conventions, t8
nan?, t174
native-endianness, t228
native-eol-style, t260
native-transcoder, t259
negative?, t173
nested engines, t429
nested let expressions, t96
new-cafe, 407
newline, 285
no-infinities-violation?, 576
no-name-violation?, t377
nodups?, 381
non-continuable-violation?, t369
nondeterministic computations, t424, 135, 139
nongenerative, t324
nongenerative, t331
nongenerative record definitions, 194, 199
nonlocal exits, t123
nonnegative?, 237
nonpositive?, 237
not, t36, t110
null-environment, t37, 339
null?, t37, t151
number->string, t191, 238
number?, t38, t151
numbers, t167
numerator, 181

object identity, t144
object->reference-address, 92
object->string, t267
object->backreferences, 420
object-counts, 54, 129
object-oriented programming, t317
objects, t3
obl, 173
occur free, t30
octet, t257
odd?, t81, t174
one-shot continuations, 130
only, 335
only import set, t346
opaque, t331
opaque record type, t330
open-bytevector-input-port, t264
open-bytevector-output-port, t265
open-fd-input-port, 258
open-fd-input/output-port, 270
open-fd-output-port, 267
open-file-input-port, t262
open-file-input/output-port, t263
open-file-output-port, t262
open-file-input, t257
open-input-output-file, t270
open-input-string, 254
open-output-file, t281, 265
open-output-string, 265
open-process-ports, 58
open-source-file, 345, 348
open-string-input-port, t265
open-string-output-port, t266
operating system, t423, 138
operations on objects, t141
operator precedence, t16
optimization, 22
optimize-level, 23, 389
optional arguments, t93
or, t63, t110
order of evaluation, t93
ordinals, 201
ormap, 129
output port, t257
output-port-buffer-mode, t273
output-port?, t270

pair?, t38, t151
pairs, t19
parameterize, t30
parameters, 5
parent, t331
parent type, t325
parent-rtd, t331
pairs, 489
pariah, 397
partition, t164
path-absolute?, t292
path-build, 292
path-extension, t292
path-first, 292
path-last, 292
path-parent, 292
path-rest, 292
path-root, 292
pattern matching, 183
pattern variable, t294
pattern variables, t61
patterns, t294
pbchunk-convert-file, 378
peek-char, t284
petite.boot, 24
petite?, t199
Petite Chez Scheme, 1, tix
phantom bytevectors, 452
phantom-bytevector-length, 453
phantom-bytevector?, 453
pointer, 168
pointers, 4
por (parallel-or), t424, 139
port, t257
port-bol?, t249
port-closed?, t249
port-eof?, t278
port-file-compressed!, 253
port-file-descriptor, 256
port-handler, 243
port-has-port-length?, 250
port-has-port-nonblocking?, 251
port-has-port-position?, t271
port-has-set-port-length?, 251
port-has-set-port-nonblocking?, 251
port-has-set-port-position!, t272
port-input-buffer, 246
port-input-count, 247
port-input-empty?, 247
port-input-index, 246
port-input-size, 246
port-length, 246
port-name, 256
port-nonblocking?, 251
port-output-buffer, 246
port-output-count, 246
port-output-full?, 246
port-output-index, 246
port-output-size, 246
port-position, t271
port-transcoder, t271
port?, t270
positive?, t173
predicate, t199
predicates, t143
prefix, 199
prefix import set, t346
prefix notation, t16
pretty-file, 272
pretty-format, 272
pretty-initial-indent, 274
pretty-line-length, 274
pretty-maximum-lines, 274
pretty-one-line-limit, 274
pretty-print, 277
pretty-standard-indent, 275
primitive procedures, 4
print-brackets, 282
print-char-name, 279
print-extended-identifiers, 283
print-gensym, 171, 282
print-graph, 202, 280
print-length, 202, 280
print-level, 5, 280
print-positive-exponent-sign, 285
print-precision, 284
print-radix, 202
print-record, 203
print-select-flonum-exponential-format, 285
print-subnormal-precision, 284
print-unicode, 285
print-vector-length, 4, 284
printi, t401, 277
procedure application, t16, t107
procedure definition, t100
procedure-arity-mask, 206
procedure-known-single-valued?, 211
procedure?, t155
procedures, 91
process, 57, 58
process ports, 298
product, t74
profile, 402
profile-clear, 402
profile-clear-database, 407
profile-dump, 398, 403
profile-dump-data, 398, 404
profile-dump-html, 398, 404
profile-dump-list, 398, 404
profile-line-number-color, 405
profile-load-data, 398, 406
profile-palette, 404
<table>
<thead>
<tr>
<th>Index</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>remove!, 146</td>
<td></td>
</tr>
<tr>
<td>remove-foreign-entry!, 146</td>
<td></td>
</tr>
<tr>
<td>remove-hash-table!, 146</td>
<td></td>
</tr>
<tr>
<td>remove-registry!, 146</td>
<td></td>
</tr>
<tr>
<td>remp, 163</td>
<td></td>
</tr>
<tr>
<td>remprop, 174</td>
<td></td>
</tr>
<tr>
<td>remq, 163</td>
<td></td>
</tr>
<tr>
<td>remq!, 146</td>
<td></td>
</tr>
<tr>
<td>remv, 144, 163</td>
<td></td>
</tr>
<tr>
<td>remv!, 146</td>
<td></td>
</tr>
<tr>
<td>rename, 338</td>
<td></td>
</tr>
<tr>
<td>rename import set, 346</td>
<td></td>
</tr>
<tr>
<td>require-nongenerative-clause, 187, 188</td>
<td></td>
</tr>
<tr>
<td>reset, 410</td>
<td></td>
</tr>
<tr>
<td>reset-cost-center!, 423</td>
<td></td>
</tr>
<tr>
<td>reset-handler, 410</td>
<td></td>
</tr>
<tr>
<td>reset-maximum-memory-bytes!, 423</td>
<td></td>
</tr>
<tr>
<td>retry, 80</td>
<td></td>
</tr>
<tr>
<td>reverse, 161</td>
<td></td>
</tr>
<tr>
<td>reverse!, 147</td>
<td></td>
</tr>
<tr>
<td>Revised Reports, 3</td>
<td></td>
</tr>
<tr>
<td>revisit, 365</td>
<td></td>
</tr>
<tr>
<td>revisit-compiled-from-port, 300, 369</td>
<td></td>
</tr>
<tr>
<td>round, 178</td>
<td></td>
</tr>
<tr>
<td>round-robin, 423, 138</td>
<td></td>
</tr>
<tr>
<td>rtd, 331</td>
<td></td>
</tr>
<tr>
<td>run-cp0, 393</td>
<td></td>
</tr>
<tr>
<td>run-time generativity, 104</td>
<td></td>
</tr>
<tr>
<td>s (short), 169</td>
<td></td>
</tr>
<tr>
<td>s8-list-&gt;bytevector, 162</td>
<td></td>
</tr>
<tr>
<td>Sactivate_thread, 109</td>
<td></td>
</tr>
<tr>
<td>Schar_value, 100</td>
<td></td>
</tr>
<tr>
<td>Scharp, 100</td>
<td></td>
</tr>
<tr>
<td>scheme, 339</td>
<td></td>
</tr>
<tr>
<td>scheme module, 339</td>
<td></td>
</tr>
<tr>
<td>Scheme shell scripts, 20</td>
<td></td>
</tr>
<tr>
<td>Scheme standard, tix</td>
<td></td>
</tr>
<tr>
<td>scheme-environment, 402</td>
<td></td>
</tr>
<tr>
<td>scheme-object, 90, 330, 377</td>
<td></td>
</tr>
<tr>
<td>scheme-pre-release, 426</td>
<td></td>
</tr>
<tr>
<td>scheme-program, 111</td>
<td></td>
</tr>
<tr>
<td>scheme-report-environment, t137, 339</td>
<td></td>
</tr>
<tr>
<td>scheme-script, 405, 411</td>
<td></td>
</tr>
<tr>
<td>scheme-start, 211, 212, 412</td>
<td></td>
</tr>
<tr>
<td>scheme-version, 432</td>
<td></td>
</tr>
<tr>
<td>scheme-version-number, 433</td>
<td></td>
</tr>
<tr>
<td>scheme.boot, 24</td>
<td></td>
</tr>
<tr>
<td>SCHEMEHEADDIRS, 161</td>
<td></td>
</tr>
<tr>
<td>Scompact_heap, 95, 105, 137</td>
<td></td>
</tr>
<tr>
<td>Scons, 104</td>
<td></td>
</tr>
<tr>
<td>scope, 125</td>
<td></td>
</tr>
<tr>
<td>scripting, 20</td>
<td></td>
</tr>
<tr>
<td>Sdeactivate_thread, 109</td>
<td></td>
</tr>
<tr>
<td>Sdestroy_thread, 109</td>
<td></td>
</tr>
<tr>
<td>sealed, 103</td>
<td></td>
</tr>
<tr>
<td>sealed record type, 130</td>
<td></td>
</tr>
<tr>
<td>segment-length, t132</td>
<td></td>
</tr>
<tr>
<td>segment-slope, t132</td>
<td></td>
</tr>
<tr>
<td>self-evaluating-vectors, 139</td>
<td></td>
</tr>
<tr>
<td>semicolon ( ; ), t7</td>
<td></td>
</tr>
<tr>
<td>Senable_expeditor, 98</td>
<td></td>
</tr>
<tr>
<td>Seof_object, 104</td>
<td></td>
</tr>
<tr>
<td>Seof_objectp, 100</td>
<td></td>
</tr>
<tr>
<td>sequence, t313</td>
<td></td>
</tr>
<tr>
<td>sequencing, t108</td>
<td></td>
</tr>
<tr>
<td>serious-condition?, t366</td>
<td></td>
</tr>
<tr>
<td>set!, 147, 110, 122</td>
<td></td>
</tr>
<tr>
<td>set-binary-port-input-buffer!, 246</td>
<td></td>
</tr>
<tr>
<td>set-binary-port-input-index!, 246</td>
<td></td>
</tr>
<tr>
<td>set-binary-port-input-size!, 246</td>
<td></td>
</tr>
<tr>
<td>set-binary-port-output-buffer!, 248</td>
<td></td>
</tr>
<tr>
<td>set-binary-port-output-index!, 248</td>
<td></td>
</tr>
<tr>
<td>set-binary-port-output-size!, 248</td>
<td></td>
</tr>
<tr>
<td>set-box!, 169</td>
<td></td>
</tr>
<tr>
<td>set-car!, 157</td>
<td></td>
</tr>
<tr>
<td>set-cdr!, 56, 157</td>
<td></td>
</tr>
<tr>
<td>set-of, 138</td>
<td></td>
</tr>
<tr>
<td>set-phantom-bytevector-length!, 429</td>
<td></td>
</tr>
<tr>
<td>set-port-bol!, 249</td>
<td></td>
</tr>
<tr>
<td>set-port-eof!, 249</td>
<td></td>
</tr>
<tr>
<td>set-port-input-buffer!, 246</td>
<td></td>
</tr>
<tr>
<td>set-port-input-index!, 246</td>
<td></td>
</tr>
<tr>
<td>set-port-input-size!, 246</td>
<td></td>
</tr>
<tr>
<td>set-port-length!, 251</td>
<td></td>
</tr>
<tr>
<td>set-port-name!, 250</td>
<td></td>
</tr>
<tr>
<td>set-port-nonblocking!, 251</td>
<td></td>
</tr>
<tr>
<td>set-port-output-buffer!, 248</td>
<td></td>
</tr>
<tr>
<td>set-port-output-index!, 248</td>
<td></td>
</tr>
<tr>
<td>set-port-output-size!, 248</td>
<td></td>
</tr>
<tr>
<td>set-port-position!, 278</td>
<td></td>
</tr>
</tbody>
</table>
Index

Sregister_boot_file_fd_segment, 98
Sregister_symbol, 106
Sretain_static_relocation, 98
Sscheme_deinit, 98
Sscheme_init, 98
Sscheme_program, 98
Sscheme_script, 98
Sscheme_start, 98
Sset_box, 102
Sset_car, 102
Sset_cdr, 102
Sset_top_level_value, 105
Sset_verbose, 98
ssize_t, 62, 66
sstats-bytes, 424
sstats-cpu, 424
sstats-difference, 425
sstats-gc-bytes, 424
sstats-gc-count, 424
sstats-gc-cpu, 424
sstats-gc-real, 424
sstats-print, 425
sstats-real, 424
sstats, 424
Sstring, 103
Sstring_length, 101
Sstring_of_length, 103
Sstring_ref, 102
Sstring_set, 102
Sstring_to_symbol, 104
Sstring_utf8, 103
Sstringp, 100
Ssymbol_to_string, 101
Ssymbolp, 100
stack objects, t52
standard-error-port, t264, 268
standard-input-port, t264, 259
standard-output-port, t264, 267
static generation, 437
statistics, 423
stencil vectors, 105
stencil-vector, 105
stencil-vector-length, 106
stencil-vector-mask, 106
stencil-vector-mask-width, 106
stencil-vector-ref, 106
stencil-vector-set!, 106
stencil-vector-truncate!, 106
stencil-vector-update, 107
stencil-vector?, 106
Stop_level_value, 105
storage management, 437
streams, t128
stretch strings, 190
string, t218, 60, 64, 68
string input port, 254
string output port, 255
string syntax, t458
string->bytevector, t287
string->immutable-string, t50, 52
string->list, t222
string->multibyte, 277
string->number, t191, 238
string->symbol, t242
string->uninterned-symbol, 772
string->utf16, t287
string->utf32, t287
string->utf8, t287
string-append, t219
string-append-immutable, 150, 152
string-ci-hash, t245
string-ci<=?, t217, 150
string-ci<?, t217, 150
string-ci=?, t217, 150
string-ci>=?, t217, 150
string-ci>?, t217, 150
string-copy, t219
string-copy!, t52
string-downcase, t221
string-fill!, t220
string-foldcase, t221
string-for-each, t122
string-grapheme-count, 153
string-grapheme-span, 153
string-hash, t245
string-length, t218
string-normalize-nfc, t222
string-normalize-nfd, t222
string-normalize-nfkc, t222
string-normalize-nfkd, t222
string-ref, t218
string-set!, t219
string-titlecase, t221
string-truncate!, t52
string-upcase, t221
string<=?, t216, 150
string<?, t216, 150
string=?, t216, 150
string>=?, t216, 150
string>? , t216, 150
string?, t138, t154
strings, t216
strip-fasl-file, 27, 377
structured forms, t6
structures, t318, 488
Strue, 103
Stry_integer32_value, 101
Stry_integer64_value, 101
Stry_integer_value, 101
Stry_unsigned32_value, 101
Stry_unsigned64_value, 101
Stry_unsigned_value, 101
sub1, 235
subset-mode, 435
subset, 146
<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>top-level-programs</td>
<td>17, 23, 303, 307</td>
</tr>
<tr>
<td>top-level-syntax</td>
<td>124</td>
</tr>
<tr>
<td>top-level-syntax?</td>
<td>125</td>
</tr>
<tr>
<td>top-level-value</td>
<td>122</td>
</tr>
<tr>
<td>trace, t42</td>
<td></td>
</tr>
<tr>
<td>trace-case-lambda</td>
<td>34</td>
</tr>
<tr>
<td>trace-define</td>
<td>38</td>
</tr>
<tr>
<td>trace-define-syntax</td>
<td>39</td>
</tr>
<tr>
<td>trace-do, t42</td>
<td>35</td>
</tr>
<tr>
<td>trace-lambda</td>
<td>33</td>
</tr>
<tr>
<td>trace-let</td>
<td>34</td>
</tr>
<tr>
<td>trace-output-port</td>
<td>35</td>
</tr>
<tr>
<td>trace-print</td>
<td>38</td>
</tr>
<tr>
<td>tracing, t42</td>
<td></td>
</tr>
<tr>
<td>transcoded-port</td>
<td>t271</td>
</tr>
<tr>
<td>transcoded-port-buffer-size</td>
<td>244</td>
</tr>
<tr>
<td>transcoded-coder</td>
<td>t259</td>
</tr>
<tr>
<td>transcoder-sol-style</td>
<td>t259</td>
</tr>
<tr>
<td>transcoder-error-handling-mode</td>
<td>t259</td>
</tr>
<tr>
<td>transcoder?</td>
<td>223</td>
</tr>
<tr>
<td>transcript, t112</td>
<td></td>
</tr>
<tr>
<td>transcript ports</td>
<td>206</td>
</tr>
<tr>
<td>transcript-cafe</td>
<td>413</td>
</tr>
<tr>
<td>transcript-off</td>
<td>412</td>
</tr>
<tr>
<td>transcript-on</td>
<td>412</td>
</tr>
<tr>
<td>transformer, t61</td>
<td></td>
</tr>
<tr>
<td>tree-copy, t44</td>
<td></td>
</tr>
<tr>
<td>true, t7</td>
<td></td>
</tr>
<tr>
<td>truncate, t177</td>
<td></td>
</tr>
<tr>
<td>truncate-file, t206</td>
<td></td>
</tr>
<tr>
<td>truncate-port, t206</td>
<td></td>
</tr>
<tr>
<td>two-way ports, t207</td>
<td></td>
</tr>
<tr>
<td>two-way streams, t239</td>
<td></td>
</tr>
<tr>
<td>type predicates, t38</td>
<td></td>
</tr>
<tr>
<td>type-descriptor, t207</td>
<td></td>
</tr>
<tr>
<td>u16*, 60, 63, 67</td>
<td></td>
</tr>
<tr>
<td>u32*, 60, 63</td>
<td></td>
</tr>
<tr>
<td>u8*, 60, 63, 67</td>
<td></td>
</tr>
<tr>
<td>u8-list-&gt;bytevector, t232</td>
<td></td>
</tr>
<tr>
<td>uint-list-&gt;bytevector, t239</td>
<td></td>
</tr>
<tr>
<td>unbox, t68</td>
<td></td>
</tr>
<tr>
<td>undefined-variable-warnings, t396</td>
<td></td>
</tr>
<tr>
<td>underscore (_), t61</td>
<td></td>
</tr>
<tr>
<td>underscore (.), t294</td>
<td></td>
</tr>
<tr>
<td>unget-char, 260</td>
<td></td>
</tr>
<tr>
<td>unget-u8, 261</td>
<td></td>
</tr>
<tr>
<td>unification, t417</td>
<td></td>
</tr>
<tr>
<td>unify, t418</td>
<td></td>
</tr>
<tr>
<td>uninterned symbols, t171</td>
<td></td>
</tr>
<tr>
<td>uninterned-symbol?, t171</td>
<td></td>
</tr>
<tr>
<td>Unix, t9</td>
<td></td>
</tr>
<tr>
<td>unless, t64, t112</td>
<td></td>
</tr>
<tr>
<td>UNLOCK, t112</td>
<td></td>
</tr>
<tr>
<td>unlock-object, 106</td>
<td>457</td>
</tr>
<tr>
<td>Term</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>vector-sort1</td>
<td>226</td>
</tr>
<tr>
<td>vector?</td>
<td>154</td>
</tr>
<tr>
<td>vectors</td>
<td>55</td>
</tr>
<tr>
<td>verify-loadability</td>
<td>367</td>
</tr>
<tr>
<td>vfasl-convert-file</td>
<td>375</td>
</tr>
<tr>
<td>violation?</td>
<td>366</td>
</tr>
<tr>
<td>virtual-register</td>
<td>432</td>
</tr>
<tr>
<td>virtual-register-count</td>
<td>432</td>
</tr>
<tr>
<td>visit</td>
<td>368</td>
</tr>
<tr>
<td>visit-compiled-from-port</td>
<td>308</td>
</tr>
<tr>
<td>void, 4</td>
<td>175</td>
</tr>
<tr>
<td>void object</td>
<td>4</td>
</tr>
<tr>
<td>void*</td>
<td>62</td>
</tr>
<tr>
<td>waiter</td>
<td>407</td>
</tr>
<tr>
<td>waiter-prompt-and-read</td>
<td>409</td>
</tr>
<tr>
<td>waiter-prompt-string</td>
<td>409</td>
</tr>
<tr>
<td>waiter-write</td>
<td>409</td>
</tr>
<tr>
<td>warning</td>
<td>353</td>
</tr>
<tr>
<td>warning?</td>
<td>367</td>
</tr>
<tr>
<td>warningf</td>
<td>354</td>
</tr>
<tr>
<td>wchar</td>
<td>63</td>
</tr>
<tr>
<td>wchar_t</td>
<td>63</td>
</tr>
<tr>
<td>weak pairs</td>
<td>443</td>
</tr>
<tr>
<td>weak pointers</td>
<td>443</td>
</tr>
<tr>
<td>weak-cons</td>
<td>443</td>
</tr>
<tr>
<td>weak-pair?</td>
<td>444</td>
</tr>
<tr>
<td>when, t64</td>
<td>112</td>
</tr>
<tr>
<td>whitespace characters, t7</td>
<td></td>
</tr>
<tr>
<td>who-condition?</td>
<td>369</td>
</tr>
<tr>
<td>winders</td>
<td></td>
</tr>
<tr>
<td>with, 4</td>
<td>87</td>
</tr>
<tr>
<td>with-continuation-mark</td>
<td>131</td>
</tr>
<tr>
<td>with-cost-center</td>
<td>426</td>
</tr>
<tr>
<td>with-exception-handler</td>
<td>360</td>
</tr>
<tr>
<td>with-implicit</td>
<td>329</td>
</tr>
<tr>
<td>with-input-from-file</td>
<td>283</td>
</tr>
<tr>
<td>with-input-from-string</td>
<td>254</td>
</tr>
<tr>
<td>with-interrupts-disabled</td>
<td>260</td>
</tr>
<tr>
<td>with-mutex</td>
<td>470</td>
</tr>
<tr>
<td>with-output-to-file</td>
<td>288</td>
</tr>
<tr>
<td>with-output-to-string</td>
<td>255</td>
</tr>
<tr>
<td>with-profile-tracker</td>
<td>449</td>
</tr>
<tr>
<td>with-source-path</td>
<td>386</td>
</tr>
<tr>
<td>with-syntax</td>
<td>304</td>
</tr>
<tr>
<td>wrapper-procedure-data</td>
<td>210</td>
</tr>
<tr>
<td>wrapper-procedure-procedure</td>
<td>210</td>
</tr>
<tr>
<td>wrapper-procedure</td>
<td>207</td>
</tr>
<tr>
<td>write, t397, t284</td>
<td></td>
</tr>
<tr>
<td>write-char</td>
<td>285</td>
</tr>
<tr>
<td>wstring</td>
<td>90</td>
</tr>
<tr>
<td>x++</td>
<td>316</td>
</tr>
<tr>
<td>zero?</td>
<td>173</td>
</tr>
</tbody>
</table>