Revised Report on the Algorithmic Language Scheme

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SUMMARY
The report gives a defining description of the programming language Scheme. Scheme is a statically scoped and properly tail-recursive dialect of the Lisp programming language invented by Guy Lewis Steele Jr. and Gerald Jay Sussman. It was designed to have an exceptionally clear and simple semantics and few different ways to form expressions. A wide variety of programming paradigms, including imperative, functional, and message passing styles, find convenient expression in Scheme.

The introduction offers a brief history of the language and of the report.

The first three chapters present the fundamental ideas of the language and describe the notational conventions used for describing the language and for writing programs in the language.

Chapters 4 and 5 describe the syntax and semantics of expressions, definitions, programs, and modules.

Chapter 6 describes Scheme’s built-in procedures, which include all of the language’s data manipulation and input/output primitives.

Chapter 7 provides a formal syntax for Scheme written in extended BNF, along with a formal denotational semantics. An example of the use of the language follows the formal syntax and semantics.

Chapter A provides a list of the standard modules and the identifiers that they export.

Chapter B provides a list of semi-standard implementation features.

The report concludes with a list of references and an alphabetic index.

*** DRAFT***
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INTRODUCTION

Programming languages should be designed not by piling feature on top of feature, but by removing the weaknesses and restrictions that make additional features appear necessary. Scheme demonstrates that a very small number of rules for forming expressions, with no restrictions on how they are composed, suffice to form a practical and efficient programming language that is flexible enough to support most of the major programming paradigms in use today.

Scheme was one of the first programming languages to incorporate first class procedures as in the lambda calculus, thereby proving the usefulness of static scope rules and block structure in a dynamically typed language. Scheme was the first major dialect of Lisp to distinguish procedures from lambda expressions and symbols, to use a single lexical environment for all variables, and to evaluate the operator position of a procedure call in the same way as an operand position. By relying entirely on procedure calls to express iteration, Scheme emphasized the fact that tail-recursive procedure calls are essentially goto's that pass arguments. Scheme was the first widely used programming language to embrace first class escape procedures, from which all previously known sequential control structures can be synthesized. A subsequent version of Scheme introduced the concept of exact and inexact numbers, an extension of Common Lisp’s generic arithmetic. More recently, Scheme became the first programming language to support hygienic macros, which permit the syntax of a block-structured language to be extended in a consistent and reliable manner.

Background

The first description of Scheme was written in 1975 [30]. A revised report [27] appeared in 1978, which described the evolution of the language as its MIT implementation was upgraded to support an innovative compiler [28]. Three distinct projects began in 1981 and 1982 to use variants of Scheme for courses at MIT, Yale, and Indiana University [23, 19, 12]. An introductory computer science textbook using Scheme was published in 1984 [3].

As Scheme became more widespread, local dialects began to diverge until students and researchers occasionally found it difficult to understand code written at other sites. Fifteen representatives of the major implementations of Scheme therefore met in October 1984 to work toward a better and more widely accepted standard for Scheme. Their report [6] was published at MIT and Indiana University in the summer of 1985. Further revision took place in the spring of 1986 [25], and in the spring of 1988 [8]. The present report reflects further revisions agreed upon in a meeting at Xerox PARC in June 1992.

We intend this report to belong to the entire Scheme community, and so we grant permission to copy it in whole or in part without fee. In particular, we encourage implementors of Scheme to use this report as a starting point for manuals and other documentation, modifying it as necessary.

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DESCRIPTION OF THE LANGUAGE

1. Overview of Scheme

1.1. Semantics

This section gives an overview of Scheme’s semantics. A detailed informal semantics is the subject of chapters 3 through 6. For reference purposes, section 7.2 provides a formal semantics of Scheme.

Following Algol, Scheme is a statically scoped programming language. Each use of a variable is associated with a lexically apparent binding of that variable.

Scheme is a dynamically typed language. Types are associated with values (also called objects) rather than with variables. Other dynamically typed languages include APL, Common Lisp, JavaScript, Perl, Python, Ruby, and Smalltalk. Statically typed languages associate types with variables and expressions as well as values, and include Algol 60, C, C++, C#, Haskell, Java, ML, and Pascal.

All objects created in the course of a Scheme computation, including procedures and continuations, have unlimited extent. No Scheme object is ever destroyed. The reason that implementations of Scheme do not (usually!) run out of storage is that they are permitted to reclaim the storage occupied by an object if they can prove that the object cannot possibly matter to any future computation. Other languages in which most objects have unlimited extent include APL, C#, Common Lisp, Haskell, Java, JavaScript, ML, Perl, Python, Ruby, and Smalltalk.

Implementations of Scheme are required to be properly tail-recursive. This allows the execution of an iterative computation in constant space, even if the iterative computation is described by a syntactically recursive procedure. Thus with a properly tail-recursive implementation, iteration is described by a syntactically recursive procedure. Scheme’s model of arithmetic is designed to remain as independent as possible of the particular ways in which numbers are represented within a computer. In Scheme, every integer is a rational number, every rational is a real, and every real is a complex number. Thus the distinction between integer and real arithmetic, so important to many programming languages, does not appear in Scheme. In its place is a distinction between exact arithmetic, which corresponds to the mathematical ideal, and inexact arithmetic on approximations. As in Common Lisp, exact arithmetic is not limited to integers.

1.2. Syntax

Scheme, like most dialects of Lisp, employs a fully parenthesized prefix notation for programs and (other) data; the grammar of Scheme generates a sublanguage of the language used for data. An important consequence of this simple, uniform representation is the susceptibility of Scheme programs and data to uniform treatment by other Scheme programs. For example, the eval procedure evaluates a Scheme program expressed as data.

The read procedure performs syntactic as well as lexical decomposition of the data it reads. The read procedure parses its input as data (section 7.1.2), not as program.

The formal syntax of Scheme is described in section 7.1.

1.3. Notation and terminology

1.3.1. Base and optional features

Every identifier defined in this report appears in one of several modules. Identifiers defined in the base module are not marked specially in the body of the report. A summary of all the standard modules and the features they provide is given in Appendix A.

Implementations must provide the base module and all the identifiers exported from it. Implementations are free to provide or omit the other modules given in this report, but each module must either be provided in its entirety, exporting no additional identifiers, or else omitted altogether.
Implementations may provide other modules not described in this report. Implementations may also extend the function of any identifier in this report, provided the extensions are not in conflict with the language reported here. In particular, implementations must support portable code by providing a syntactic mode that preempts no lexical conventions of this report.

1.3.2. Error situations and unspecified behavior

When speaking of an error situation, this report uses the phrase “an error is signalled” to indicate that implementations must detect and report the error. If such wording does not appear in the discussion of an error, then implementations are not required to detect or report the error, though they are encouraged to do so. An error situation that implementations are not required to detect is usually referred to simply as “an error.”

For example, it is an error for a procedure to be passed an argument that the procedure is not explicitly specified to handle, even though such domain errors are seldom mentioned in this report. Implementations may extend a procedure’s domain of definition to include such arguments.

This report uses the phrase “may report a violation of an implementation restriction” to indicate circumstances under which an implementation is permitted to report that it is unable to continue execution of a correct program because of some restriction imposed by the implementation. Implementation restrictions are of course discouraged, but implementations are encouraged to report violations of implementation restrictions.

For example, an implementation may report a violation of an implementation restriction if it does not have enough storage to run a program.

If the value of an expression is said to be “unspecified,” then the expression must evaluate to some object without signalling an error, but the value depends on the implementation; this report explicitly does not say what value should be returned.

In addition to errors signalled by situations described in this report, programmers may signal their own errors and handle signalled errors as described in section 6.5.

1.3.3. Entry format

Chapters 4 and 6 are organized into entries. Each entry describes one language feature or a group of related features, where a feature is either a syntactic construct or a built-in procedure. An entry begins with one or more header lines of the form

```
-template module category
```

for identifiers in the `base` module, or

```
-template category
```

where `module` is the short name of a module as defined in Appendix A.

If `category` is “syntax”, the entry describes an expression type, and the template gives the syntax of the expression type. Components of expressions are designated by syntactic variables, which are written using angle brackets, for example, `<expression>` , `<variable>`. Syntactic variables should be understood to denote segments of program text; for example, `<expression> `stands for any string of characters which is a syntactically valid expression. The notation

```
<thing1> ...
```

indicates zero or more occurrences of a `<thing>`, and

```
<thing1> <thing2> ...
```

indicates one or more occurrences of a `<thing>`.

If `category` is “procedure”, then the entry describes a procedure, and the header line gives a template for a call to the procedure. Argument names in the template are italicized. Thus the header line

```
(vector-ref vector k)
```

indicates that the built-in procedure `vector-ref` takes two arguments, a vector `vector` and an exact non-negative integer `k` (see below). The header lines

```
(make-vector)
```

```
(make-vector k fill)
```

indicate that the `make-vector` procedure must be defined to take either one or two arguments.

It is an error for an operation to be presented with an argument that it is not specified to handle. For succinctness, we follow the convention that if an argument name is also the name of a type listed in section 3.2, then that argument must be of the named type. For example, the header line for `vector-ref` given above dictates that the first argument to `vector-ref` must be a vector. The following naming conventions also imply type restrictions:

```
obj list, list1, ... listj, ...

z, z1, ... zn, ...
x, x1, ... xj, ...
y, y1, ... yk, ...
q, q1, ... qk, ...
n, n1, ... nj, ...
k, k1, ... kj, ...
```

```
any object
list (see section 6.3.2)
complex number
real number
rational number
integer
```

1.3.4. Evaluation examples

The symbol “⇒” used in program examples should be read “evaluates to.” For example,

```
(* 5 8) ⇒ 40
```
means that the expression \( (* 5 8) \) evaluates to the object \( 40 \). Or, more precisely: the expression given by the sequence of characters \( (* 5 8) \) evaluates, in the initial environment, to an object that may be represented externally by the sequence of characters \( \text{"40"} \). See section 3.3 for a discussion of external representations of objects.

### 1.3.5. Naming conventions

By convention, the names of procedures that always return a boolean value usually end in \( \text{"?"} \). Such procedures are called predicates.

By convention, the names of procedures that store values into previously allocated locations (see section 3.4) usually end in \( \text{"!"} \). Such procedures are called mutation procedures. By convention, the value returned by a mutation procedure is unspecified.

By convention, \( \text{"->"} \) appears within the names of procedures that take an object of one type and return an analogous object of another type. For example, \( \text{list->vector} \) takes a list and returns a vector whose elements are the same as those of the list.

### 2. Lexical conventions

This section gives an informal account of some of the lexical conventions used in writing Scheme programs. For a formal syntax of Scheme, see section 7.1.

#### 2.1. Identifiers

Most identifiers allowed by other programming languages are also acceptable to Scheme. The precise rules for forming identifiers vary among implementations of Scheme, but in all implementations a sequence of letters, digits, and "extended alphabetic characters" that does not have a prefix which is a valid number is an identifier. However, the . token used in the list syntax is not an identifier. Here are some examples of identifiers:

```scheme
lambda      q
list->vector +soup+
+           V17a
<=?          a34kTMNs
->string    ...
the-word-recursion-has-many-meanings
```

Extended alphabetic characters may be used within identifiers as if they were letters. The following are always permitted as alphabetic characters (but implementations may allow a variety of other characters in identifiers):

```
! $ % & * + - . / < = > ? @ ^ _ ` ~
```

In addition, any character can be used within an identifier when specified via an (inline hex escape). For example, the identifier \( \text{\textbackslash x65;\textbackslash llo} \) is the same as the identifier \( \text{Hello} \), and in an implementation which has the appropriate Unicode character the identifier \( \text{\textbackslash x3bb;} \) is the same as the identifier \( \lambda \).

As a convenience, identifiers may also be written as a sequence of characters enclosed within vertical bars (|), analogous to string literals. Vertical bars and other characters can be included in the identifier with an (inline hex escape). Thus the identifier \( |\text{foo bar}| \) is the same as the identifier \( \text{foo}\text{x20;bar} \).

See section 7.1.1 for a formal syntax of identifiers.

Identifiers have two uses within Scheme programs:

- Any identifier may be used as a variable or as a syntactic keyword (see sections 3.1 and 4.3).
- When an identifier appears as a literal or within a literal (see section 4.1.2), it is being used to denote a symbol (see section 6.3.3).

In contrast with earlier revisions of the report [2], the syntax of data distinguishes upper and lower case in identifiers and in characters specified via their names.

Implementors may wish to support case-insensitive syntax for backward compatibility or other reasons. If they do so, they should adopt the following optional directives to control case folding.

```scheme
#!fold-case
#!no-fold-case
```

These directives may appear anywhere comments may appear and are treated as comments, except that they affect the reading of subsequent lexemes. The \( \#!\text{fold-case} \) causes the reader to case-fold (as if by \( \text{string-foldcase} \)) each (identifier) and (character name). The \( \#!\text{no-fold-case} \) directive causes the reader to return to the default, non-folding behavior. The scope of these directives is all subsequent read operations for the port from which they are read; no other ports are affected.

#### 2.2. Whitespace and comments

Whitespace characters are spaces and newlines. (Implementations typically provide additional whitespace characters such as tab or page break.) Whitespace is used for improved readability and as necessary to separate tokens from each other, a token being an indivisible lexical unit such as an identifier or number, but is otherwise insignificant. Whitespace may occur between any two tokens, but not within a token. Whitespace may also occur inside a string, where it is significant.
The lexical syntax includes several comment forms. Comments are treated exactly like whitespace.

A semicolon (;) indicates the start of a line comment. The comment continues to the end of the line on which the semicolon appears.

Another way to indicate a comment is to prefix a ⟨datum⟩ (cf. section 7.1.2) with #; possibly with ⟨interlexeme space⟩ before the ⟨datum⟩. The comment consists of the comment prefix #; and the ⟨datum⟩ together. This notation is useful for “commenting out” sections of code.

Block comments may be indicated with properly nested #| and |# pairs.

```scheme
#|The FACT procedure computes the factorial of a non-negative integer.
|#
(define fact
 (lambda (n)
   (if (= n 0)
     #; (= n 1)
     1 ;Base case: return 1
     (* n (fact (- n 1))))))
```

2.3. Other notations

For a description of the notations used for numbers, see section 6.2.

. + - These are used in numbers, and may also occur anywhere in an identifier. A delimited plus or minus sign by itself is also an identifier. A delimited period (not occurring within a number or identifier) is used in the notation for pairs (section 6.3.2), and to indicate a rest-parameter in a formal parameter list (section 4.1.4).

( ) Parentheses are used for grouping and to notate lists (section 6.3.2).

' The single quote character is used to indicate literal data (section 4.1.2).

' The backquote character is used to indicate almost-constant data (section 4.2.8).

, @ The character comma and the sequence comma at-sign are used in conjunction with backquote (section 4.2.8).

" The double quote character is used to delimit strings (section 6.3.5).

\ Backslash is used in the syntax for character constants (section 6.3.4) and as an escape character within string constants (section 6.3.5) and identifiers (section 7.1.1).
3.2. Disjointness of types

No object satisfies more than one of the following predicates:

- boolean?
- symbol?
- char?
- vector?
- port?
- number?
- string?
- pair?
- blob?
- procedure?

These predicates define the types boolean, pair, symbol, number, char (or character), string, vector, blob, port, and procedure. The empty list is a special object of its own type; it satisfies none of the above predicates.

Although there is a separate boolean type, any Scheme value can be used as a boolean value for the purpose of a conditional test. As explained in section 6.3.1, all values count as true in such a test except for #f. This report uses the word “true” to refer to any Scheme value except #f, and the word “false” to refer to #f.

3.3. External representations

An important concept in Scheme (and Lisp) is that of the external representation of an object as a sequence of characters. For example, an external representation of the integer 28 is the sequence of characters “28”, and an external representation of a list consisting of the integers 8 and 13 is the sequence of characters “(8 13)”. The external representation of an object is not necessarily unique. The integer 28 also has representations “#e28.000” and “#x1c”, and the list in the previous paragraph also has the representations “(08 13)” and “(8 . (13 . ()))” (see section 6.3.2).

Many objects have standard external representations, but some, such as procedures, do not have standard representations (although particular implementations may define representations for them).

An external representation may be written in a program to obtain the corresponding object (see quote, section 4.1.2).

External representations can also be used for input and output. The procedure read (section 6.7.2) parses external representations, and the procedure write (section 6.7.3)generates them. Together, they provide an elegant and powerful input/output facility.

Note that the sequence of characters “(* 2 6)” is not an external representation of the integer 8, even though it is an expression evaluating to the integer 8; rather, it is an external representation of a three-element list, the elements of which are the symbol * and the integers 2 and 6. Scheme’s syntax has the property that any sequence of characters that is an expression is also the external representation of some object. This can lead to confusion, since it may not be obvious out of context whether a given sequence of characters is intended to denote data or program, but it is also a source of power, since it facilitates writing programs such as interpreters and compilers that treat programs as data (or vice versa).

The syntax of external representations of various kinds of objects accompanies the description of the primitives for manipulating the objects in the appropriate sections of chapter 6.

3.4. Storage model

Variables and objects such as pairs, vectors, and strings implicitly denote locations or sequences of locations. A string, for example, denotes as many locations as there are characters in the string. (These locations need not correspond to a full machine word.) A new value may be stored into one of these locations using the string-set! procedure, but the string continues to denote the same locations as before.

An object fetched from a location, by a variable reference or by a procedure such as car, vector-ref, or string-ref, is equivalent in the sense of eqv? (section 6.1) to the object last stored in the location before the fetch.

Every location is marked to show whether it is in use. No variable or object ever refers to a location that is not in use. Whenever this report speaks of storage being allocated for a variable or object, what is meant is that an appropriate number of locations are chosen from the set of locations that are not in use, and the chosen locations are marked to indicate that they are now in use before the variable or object is made to denote them.

In many systems it is desirable for constants (i.e. the values of literal expressions) to reside in read-only-memory. To express this, it is convenient to imagine that every object that denotes locations is associated with a flag telling whether that object is mutable or immutable. In such systems literal constants and the strings returned by symbol->string are immutable objects, while all objects created by the other procedures listed in this report are mutable. It is an error to attempt to store a new value into a location that is denoted by an immutable object.
3.5. Proper tail recursion

Implementations of Scheme are required to be *properly tail-recursive*. Procedure calls that occur in certain syntactic contexts defined below are ‘tail calls’. A Scheme implementation is properly tail-recursive if it supports an unbounded number of active tail calls. A call is *active* if the called procedure may still return. Note that this includes calls that may be returned from either by the current continuation or by continuations captured earlier by *call-with-current-continuation* that are later invoked. In the absence of captured continuations, calls could return at most once and the active calls would be those that had not yet returned. A formal definition of proper tail recursion can be found in [10].

**Rationale:**

Intuitively, no space is needed for an active tail call because the continuation that is used in the tail call has the same semantics as the continuation passed to the procedure containing the call. Although an improper implementation might use a new continuation in the call, a return to this new continuation would be followed immediately by a return to the continuation passed to the procedure. A properly tail-recursive implementation returns to that continuation directly.

Proper tail recursion was one of the central ideas in Steele and Sussman’s original version of Scheme. Their first Scheme interpreter implemented both functions and actors. Control flow was expressed using actors, which differed from functions in that they passed their results on to another actor instead of returning to a caller. In the terminology of this section, each actor finished with a tail call to another actor.

Steele and Sussman later observed that in their interpreter the code for dealing with actors was identical to that for functions and thus there was no need to include both in the language.

A *tail call* is a procedure call that occurs in a *tail context*. Tail contexts are defined inductively. Note that a tail context is always determined with respect to a particular lambda expression.

- The last expression within the body of a lambda expression, shown as (tail expression) below, occurs in a tail context. The same is true of the bodies of a *case-lambda* expression.

```
(lamb ξ (formals)
  (definition)* (expression)* (tail expression))
```

- If one of the following expressions is in a tail context, then the subexpressions shown as (tail expression) are in a tail context. These were derived from rules in the grammar given in chapter 7 by replacing some occurrences of (expression) with (tail expression). Only those rules that contain tail contexts are shown here.

```
(if (expression) (tail expression) (tail expression))
(if (expression) (tail expression))
(cond (cond clause)+)
(cond (cond clause)* (else (tail sequence)))
(case (expression)
  (case clause)*)
(case (expression)
  (case clause)*
  (else (tail sequence)))
(and (expression)* (tail expression))
(or (expression)* (tail expression))
(let ((binding spec)*) (tail body))
(let (variable) ((binding spec)*) (tail body))
(let* ((binding spec)*) (tail body))
(letrec ((binding spec)*) (tail body))
(letrec* ((binding spec)*) (tail body))
(let-syntax ((syntax spec)*) (tail body))
(letrec-syntax ((syntax spec)*) (tail body))
(begin (tail sequence))
(do ((iteration spec)*
    ((test) (tail sequence))
    (expression)*)
  where
  (cond clause) → ((test) (tail sequence))
  (case clause) → ((datum)*) (tail sequence))
  (tail body) → (definition)* (tail sequence)
  (tail sequence) → (expression)* (tail expression)
```

- If a *cond* expression is in a tail context, and has a clause of the form ((expression1) => (expression2)) then the (implied) call to the procedure that results from the evaluation of (expression1) is in a tail context. (expression2) itself is not in a tail context.

Certain built-in procedures are also required to perform tail calls. The first argument passed to *apply* and to *call-with-current-continuation*, and the second argument passed to *call-with-values*, must be called via a tail call. Similarly, *eval* must evaluate its first argument as if it were in tail position within the *eval* procedure.

In the following example the only tail call is the call to *f*. None of the calls to *g* or *h* are tail calls. The reference to *x* is in a tail context, but it is not a call and thus is not a tail call.

---

8 Revised 7
4. Expressions

Expression types are categorized as primitive or derived. Primitive expression types include variables and procedure calls. Derived expression types are not semantically primitive, but can instead be defined as macros. With the exception of quasiquote, whose macro definition is complex, suitable definitions of the derived expressions are given in section 7.3.

4.1. Primitive expression types

4.1.1. Variable references

⟨variable⟩ syntax

An expression consisting of a variable (section 3.1) is a variable reference. The value of the variable reference is the value stored in the location to which the variable is bound. It is an error to reference an unbound variable.

(define x 28)

x \Rightarrow 28

4.1.2. Literal expressions

⟨quote ⟨datum⟩⟩ syntax

'⟨datum⟩ syntax

⟨constant⟩ syntax

-quote {datum}) evaluates to ⟨datum⟩. ⟨Datum⟩ may be any external representation of a Scheme object (see section 3.3). This notation is used to include literal constants in Scheme code.

(quote a) \Rightarrow a
(quote #(a b c)) \Rightarrow #(a b c)
(quote (+ 1 2)) \Rightarrow (+ 1 2)

(quote {datum}) may be abbreviated as '⟨datum⟩. The two notations are equivalent in all respects.

Numerical constants, string constants, character constants, and boolean constants evaluate “to themselves”; they need not be quoted.

'"abc" \Rightarrow "abc"
"abc" \Rightarrow "abc"
'145932 \Rightarrow 145932
145932 \Rightarrow 145932
'#t \Rightarrow #t
#t \Rightarrow #t

As noted in section 3.4, it is an error to alter a constant (i.e. the value of a literal expression) using a mutation procedure like set-car! or string-set!.

4.1.3. Procedure calls

⟨⟨operator⟩ ⟨operand⟩1⟩ ...⟩ syntax

A procedure call is written by simply enclosing in parentheses expressions for the procedure to be called and the arguments to be passed to it. The operator and operand expressions are evaluated (in an unspecified order) and the resulting procedure is passed the resulting arguments.

(+ 3 4) \Rightarrow 7
((if #f + *) 3 4) \Rightarrow 12

A number of procedures are available as the values of variables in the initial environment; for example, the addition and multiplication procedures in the above examples are the values of the variables + and *. New procedures are created by evaluating lambda expressions (see section 4.1.4). Procedure calls may return any number of values (see values in section 6.4). With the exception of values the procedures available in the initial environment return one value or, for procedures such as apply, pass on the values returned by a call to one of their arguments.

Procedure calls are also called combinations.

Note: In contrast to other dialects of Lisp, the order of evaluation is unspecified, and the operator expression and the operand expressions are always evaluated with the same evaluation rules.

Note: Although the order of evaluation is otherwise unspecified, the effect of any concurrent evaluation of the operator and operand expressions is constrained to be consistent with some sequential order of evaluation. The order of evaluation may be chosen differently for each procedure call.

Note: In many dialects of Lisp, the empty combination, (), is a legitimate expression. In Scheme, combinations must have at least one subexpression, so () is not a syntactically valid expression.
## 4.1.4. Procedures

\[
\text{Syntax:}\; \text{\{Formals\}}\; \text{should be a formal arguments list as described below, and \{body\} should be a sequence of one or more expressions.}
\]

\[
\text{Semantics: A lambda expression evaluates to a procedure. The environment in effect when the lambda expression was evaluated is remembered as part of the procedure. When the procedure is later called with some actual arguments, the environment in which the lambda expression was evaluated will be extended by binding the variables in the formal argument list to fresh locations, and the expressions in the body of the lambda expression will be evaluated sequentially in the extended environment. The result(s) of the last expression in the body will be returned as the result(s) of the procedure call.}
\]

\[
\begin{align*}
\text{(lambda \{formals\} \{body\})} & \quad \implies \quad \text{a procedure} \\
(((\text{lambda } (x) (+ x x)) 4) & \quad \implies \quad 8 \\
\text{define reverse-subtract} & \\
\text{\quad (lambda } (x y) (- y x)) & \quad \implies \quad 3 \\
\text{define add4} & \\
\text{\quad (let \((x 4)) \text{\quad (lambda } (y) (+ x y)))} & \quad \implies \quad 10
\end{align*}
\]

\[
\text{(Formals) should have one of the following forms:}
\]

- \{\text{variable}_1, \ldots, \text{variable} \_n\}: These procedure takes a fixed number of arguments; when the procedure is called, the arguments will be stored in the bindings of the corresponding variables.

- \{\text{variable}\}: The procedure takes any number of arguments; when the procedure is called, the sequence of actual arguments is converted into a newly allocated list, and the list is stored in the binding of the \{variable\}.

- \{\text{variable}_1, \ldots, \text{variable}_n, \text{variable}_n+1\}: If a space-delimited period precedes the last variable, then the procedure takes \(n\) or more arguments, where \(n\) is the number of formal arguments before the period (there must be at least one). The value stored in the binding of the last variable will be a newly allocated list of the actual arguments left over after all the other actual arguments have been matched up against the other formal arguments.

It is an error for a \{variable\} to appear more than once in \{formals\}.

\[
\begin{align*}
\text{(lambda } x) \; 3 \; 4 \; 5 \; 6 & \quad \implies \quad (3 \; 4 \; 5 \; 6) \\
\text{(lambda } x \; y \; z) \; z & \quad \implies \quad (5 \; 6)
\end{align*}
\]

Each procedure created as the result of evaluating a \text{lambda} expression is (conceptually) tagged with a storage location, in order to make \text{eqv?} and \text{eq?} work on procedures (see section 6.1).

## 4.1.5. Conditionals

\[
\text{(if} \; \{\text{test}\} \; \{\text{consequent}\} \; \{\text{alternate}\})
\]

\[
\text{Syntax: \{Test\}, \{consequent\}, and \{alternate\} may be arbitrary expressions.}
\]

\[
\text{Semantics: An if expression is evaluated as follows: first, \{test\} is evaluated. If it yields a true value (see section 6.3.1), then \{consequent\} is evaluated and its value(s) is(are) returned. Otherwise \{alternate\} is evaluated and its value(s) is(are) returned. If \{test\} yields a false value and no \{alternate\} is specified, then the result of the expression is unspecified.}
\]

\[
\begin{align*}
\text{(if} \; (> \; 3 \; 2) & \; \text{'yes} \; \text{'no}) \quad \implies \quad \text{yes} \\
\text{(if} \; (> \; 2 \; 3) & \; \text{'yes} \; \text{'no}) \quad \implies \quad \text{no} \\
\text{(if} \; (> \; 3 \; 2) & \; \text{(-} \; 3 \; 2) \\
\text{\quad (+} \; 3 \; 2)) \quad \implies \quad 1
\end{align*}
\]

## 4.1.6. Assignments

\[
\text{(set!} \; \{\text{variable}\} \; \{\text{expression}\})
\]

\[
\text{(Expression) is evaluated, and the resulting value is stored in the location to which \{variable\} is bound. \{Variable\} must be bound either in some region enclosing the set! expression or at top level. The result of the set! expression is unspecified.}
\]

\[
\begin{align*}
\text{(define } \text{x} \; 2) & \quad \implies \quad 3 \\
\text{(+} \; \text{x} \; 1) & \quad \implies \quad \text{unspecified} \\
\text{(set!} \; \text{x} \; 4) & \quad \implies \quad 5
\end{align*}
\]

### 4.2. Derived expression types

The constructs in this section are hygienic, as discussed in section 4.3. For reference purposes, section 7.3 gives macro definitions that will convert most of the constructs described in this section into the primitive constructs described in the previous section.
4.2.1. Conditionals

\[ \text{cond} \ (\text{clause}_1) \ (\text{clause}_2) \ldots \]  library syntax

Syntax: Each (clause) should be of the form

\[ (\text{test}) \ (\text{expression}_1) \ldots \]

where (test) is any expression. Alternatively, a (clause) may be of the form

\[ (\text{test} \Rightarrow (\text{expression})) \]

The last (clause) may be an “else clause,” which has the form

\[ (\text{else} \ (\text{expression}_1) \ (\text{expression}_2) \ldots) \]

Semantics: A cond expression is evaluated by evaluating the (test) expressions of successive (clause)s in order until one of them evaluates to a true value (see section 6.3.1). When a (test) evaluates to a true value, then the remaining (expression)s in its (clause) are evaluated in order, and the result(s) of the last (expression) in the (clause) is(are) returned as the result(s) of the entire cond expression.

If the selected (clause) contains only the (test) and no (expression)s, then the value of the (test) is returned as the result. If the selected (clause) uses the \( \Rightarrow \) alternate form, then the (expression) is evaluated. Its value must be a procedure that accepts one argument; this procedure is then called on the value of the (test) and the value(s) returned by this procedure is(are) returned by the cond expression.

If all (test)s evaluate to false values, and there is no else clause, then the result of the conditional expression is unspecified; if there is an else clause, then its (expression)s are evaluated, and the value(s) of the last one is(are) returned.

\begin{align*}
(\text{cond} \ ((> 3 2) \ 'greater) & \Rightarrow \text{greater} \\
(\text{cond} \ ((> 3 2) \ 'less)) & \Rightarrow \text{less} \\
(\text{else} \ 'equal) & \Rightarrow \text{equal} \\
(\text{cond} \ ((\text{assv} \ 'b \ '((a 1) (b 2))) \Rightarrow \text{cadr}) & \Rightarrow 2
\end{align*}

\[ \text{case} \ (\text{key}) \ (\text{clause}_1) \ (\text{clause}_2) \ldots \]

library syntax

Syntax: (Key) may be any expression. Each (clause) should have the form

\[ ((\text{datum}_1) \ldots) \ (\text{expression}_1) \ (\text{expression}_2) \ldots \]

where each (datum) is an external representation of some object. All the (datum)s must be distinct. Alternatively, a (clause) may be of the form

\[ ((\text{datum}_1) \ldots) \Rightarrow (\text{expression}) \]

The last (clause) may be an “else clause,” which has one of the forms

\[ (\text{else} \ (\text{expression}_1) \ (\text{expression}_2) \ldots) \]

or

\[ (\text{else} \Rightarrow (\text{expression})). \]

Semantics: A case expression is evaluated as follows. (Key) is evaluated and its result is compared against each (datum). If the result of evaluating (key) is equivalent (in the sense of eqv?; see section 6.1) to a (datum), then the expressions in the corresponding (clause) are evaluated from left to right and the result(s) of the last expression in the (clause) is(are) returned as the result(s) of the case expression.

If the result of evaluating (key) is different from every (datum), then if there is an else clause its expressions are evaluated and the result(s) of the last is(are) the result(s) of the case expression; otherwise the result of the case expression is unspecified.

If the selected (clause) or else clause uses the \( \Rightarrow \) alternate form, then the (expression) is evaluated. Its value must be a procedure that accepts one argument; this procedure is then called on the value of the (key) and the value(s) returned by this procedure is(are) returned by the case expression.

\begin{align*}
(\text{case} \ (* \ 2 \ 3) & \Rightarrow \text{prime} \\
((2 \ 3 \ 5 \ 7) \ 'prime) & \Rightarrow \text{composite} \\
(\text{case} \ (\text{car} \ 'c \ d)) & \Rightarrow \text{unspecified} \\
((\text{a} \ 'a)) & \Rightarrow \text{c} \\
((\text{b} \ 'b)) & \Rightarrow \text{c} \\
((\text{a} \ 'a)) & \Rightarrow \text{c} \\
((\text{b} \ 'b)) & \Rightarrow \text{c}
\end{align*}

\[ (\text{and} \ (\text{test}_1) \ldots) \]

library syntax

The (test) expressions are evaluated from left to right, and the value of the first expression that evaluates to a false value (see section 6.3.1) is returned. Any remaining expressions are not evaluated. If all the expressions evaluate to true values, the value of the last expression is returned.

If there are no expressions then \#t is returned.

\begin{align*}
(\text{and} \ (= \ 2 \ 2) & \Rightarrow \#t \\
(\text{and} \ (= \ 2 \ 2) \ (< \ 2 \ 1)) & \Rightarrow \#f \\
(\text{and} \ 1 \ 2 \ 'c \ '(f \ g)) & \Rightarrow \text{f g} \\
(\text{and}) & \Rightarrow \#t
\end{align*}

\[ (\text{or} \ (\text{test}_1) \ldots) \]

library syntax

The (test) expressions are evaluated from left to right, and the value of the first expression that evaluates to a true value (see section 6.3.1) is returned. Any remaining expressions are not evaluated. If all expressions evaluate to false values, the value of the last expression is returned.

If there are no expressions then \#f is returned.
4.2.2. Binding constructs

The four binding constructs let, let*, letrec, and letrec* give Scheme a block structure, like Algol 60. The syntax of the three constructs is identical, but they differ in the regions they establish for their variable bindings. In a let expression, the initial values are computed before any of the variables become bound; in a let* expression, the bindings and evaluations are performed sequentially; while in letrec and letrec* expressions, all the bindings are in effect while their initial values are being computed, thus allowing mutually recursive definitions.

(let (bindings) (body))  
Syntax: (Bindings) should have the form
  (⟨(variable1) (init11)⟩ ...),
where each (init) is an expression, and ⟨body⟩ should be a sequence of one or more expressions. It is an error for a (variable) to appear more than once in the list of variables being bound.

Semantics: The (init)s are evaluated in the current environment (in some unspecified order), the (variable)s are bound to fresh locations holding the results, the (body) is evaluated in the extended environment, and the value(s) of the last expression in (body) is(are) returned. Each binding of a (variable) has (body) as its region.

(let ((x 2) (y 3))  
(* x y))  
⇒ 6

(let ((x 2) (y 3))  
(let ((x 7)  
(z (+ x y)))  
(* z x)))  
⇒ 35

See also named let, section 4.2.4.

(let* (bindings) (body))  
library syntax
Syntax: (Bindings) should have the form
  (⟨(variable1) (init11)⟩ ...),
and ⟨body⟩ should be a sequence of one or more expressions.

Semantics: Let* is similar to let, but the bindings are performed sequentially from left to right, and the region of a binding indicated by (⟨variable⟩ (init)) is that part of the let* expression to the right of the binding. Thus the second binding is done in an environment in which the first binding is visible, and so on.

(let* ((x 2) (y 3))  
(let* ((x 7)  
(z (+ x y)))  
(* z x)))  
⇒ 70

(letrec (bindings) (body))  
library syntax
Syntax: (Bindings) should have the form
  (⟨(variable1) (init11)⟩ ...),
and ⟨body⟩ should be a sequence of one or more expressions. It is an error for a (variable) to appear more than once in the list of variables being bound.

Semantics: The (variable)s are bound to fresh locations holding undefined values, the (init)s are evaluated in the resulting environment (in some unspecified order), each (variable) is assigned to the result of the corresponding (init), the (body) is evaluated in the resulting environment, and the value(s) of the last expression in (body) is(are) returned. Each binding of a (variable) has the entire letrec expression as its region, making it possible to define mutually recursive procedures.

(letrec ((even? 88))  
(lamb (n)  
(if (zero? n)  
#t  
(odd? (- n 1))))  
(od?  
(lamb (n)  
(if (zero? n)  
#f  
(even? (- n 1))))))  
(even? 88))  
⇒ #t

One restriction on letrec is very important: it must be possible to evaluate each (init) without assigning or referring to the value of any (variable). If this restriction is violated, then it is an error. The restriction is necessary because Scheme passes arguments by value rather than by name. In the most common uses of letrec, all the (init)s are lambda expressions and the restriction is satisfied automatically. Another restriction is that the continuation of each (init) should not be invoked more than once.

(letrec* (bindings) (body))  
library syntax
Syntax: (Bindings) should have the form
  (⟨(variable1) (init11)⟩ ...),
and ⟨body⟩ should be a sequence of one or more expressions. It is an error for a (variable) to appear more than once in the list of variables being bound.

Semantics: The (variable)s are bound to fresh locations, each (variable) is assigned in left-to-right order to the result of evaluating the corresponding (init), the (body) is
evaluated in the resulting environment, and the values of the last expression in \langle body \rangle are returned. Despite the left-to-right evaluation and assignment order, each binding of a (variable) has the entire letrec* expression as its region, making it possible to define mutually recursive procedures.

In all four constructs, the continuation of each expression used to compute initial values must not be invoked more than once.

\[
\text{letrec* } ((\ p \\ (\lambda (x) \\ (+ 1 (q (- x 1))))\\) \\ (q \\ (\lambda (y) \\ (if (zero? y) \\ 0 \\ (+ 1 (p (- y 1)))))\\) \\ (x (p 5)) \\ (y x)) 
\rightarrow 5
\]

It must be possible to evaluate each \langle init \rangle without assigning or referring to the value of the corresponding \langle variable \rangle or the \langle variable \rangle of any of the bindings that follow it in \langle bindings \rangle.

### 4.2.3. Sequencing

\[
\text{begin } \langle \text{expression}_1 \rangle \ (\text{expression}_2) \ldots \ \text{library syntax}
\]

The \langle expression \rangle\’s are evaluated sequentially from left to right, and the value(s) of the last \langle expression \rangle is(are) returned. This expression type is used to sequence side effects such as input and output.

\[
\text{define } x 0
\]

\[
\text{begin } \langle \text{set! } x 5 \rangle \\
(+ x 1)) 
\rightarrow 6
\]

\[
\text{begin } \langle \text{display } \text{"4 plus 1 equals \"} \rangle \\
\text{display } (+ 4 1)) 
\rightarrow \text{unspecified and prints 4 plus 1 equals 5}
\]

### 4.2.4. Iteration

\[
\text{do } ((\langle \text{variable} \rangle \langle \text{init} \rangle \langle \text{step} \rangle) \\
\ (\langle \text{test} \rangle \langle \text{expression} \rangle \ldots) \\
\ (\langle \text{command} \rangle \ldots) 
\]

Do is an iteration construct. It specifies a set of variables to be bound, how they are to be initialized at the start, and how they are to be updated on each iteration. When a termination condition is met, the loop exits after evaluating the \langle expression \rangle\’s.

Do expressions are evaluated as follows: The \langle init \rangle expressions are evaluated (in some unspecified order), the \langle variable \rangle\’s are bound to fresh locations, the results of the \langle init \rangle expressions are stored in the bindings of the \langle variable \rangle\’s, and then the iteration phase begins.

Each iteration begins by evaluating \langle test \rangle; if the result is false (see section 6.3.1), then the \langle command \rangle expressions are evaluated in order for effect, the \langle step \rangle expressions are evaluated in some unspecified order, the \langle variable \rangle\’s are bound to fresh locations, the results of the \langle step \rangle\’s are stored in the bindings of the \langle variable \rangle\’s, and the next iteration begins.

If \langle test \rangle evaluates to a true value, then the \langle expression \rangle\’s are evaluated from left to right and the value(s) of the last \langle expression \rangle is(are) returned. If no \langle expression \rangle\’s are present, then the value of the do expression is unspecified.

The region of the binding of a \langle variable \rangle consists of the entire do expression except for the \langle init \rangle\’s. It is an error for a \langle variable \rangle to appear more than once in the list of do variables.

A \langle step \rangle may be omitted, in which case the effect is the same as if \langle variable \rangle \langle \langle variable \rangle \langle \langle variable \rangle \rangle \rangle had been written instead of \langle variable \rangle \langle \langle variable \rangle \rangle.

\[
\text{do } ((\langle \text{vec } \text{make-vector } 5 \rangle) \\
\ (i 0 (+ i 1))) \\
\ ( (= i 5) \langle \text{vec} \rangle) \\
\ (\langle \text{vector-set! } \text{vec } i 1 \rangle) 
\rightarrow #(0 1 2 3 4)
\]

\[
\text{let } ((\langle x \langle 1 \ 3 \ 5 \ 7 \ 9 \rangle \rangle) \\
\ (do ((\langle x x \langle \text{cdr } x \rangle \rangle) \\
\ (\langle \text{sum } 0 (+ \text{sum } (\text{car } x)) \rangle) \\
\ ((\langle \text{null? } x \rangle \text{sum})丙) 
\rightarrow 25
\]

“Named let” is a variant on the syntax of let which provides a more general looping construct than do and may also be used to express recursions. It has the same syntax and semantics as ordinary let except that \langle variable \rangle is bound within \langle body \rangle to a procedure whose formal arguments are the bound variables and whose body is \langle body \rangle. Thus the execution of \langle body \rangle may be repeated by invoking the procedure named by \langle variable \rangle.

\[
\text{let loop } ((\langle \text{numbers } \langle 3 \ -2 \ 1 \ 6 \ -5 \rangle \rangle) \\
\ (\text{nonneg } '()) \\
\ (\text{neg } '()) \\
\ (\langle \text{cond } \langle \langle \text{null? } \text{numbers} \rangle \langle \text{list } \text{nonneg } \text{neg} \rangle \rangle) \\
\ (\langle \text{loop } \langle \text{cdr } \text{numbers} \rangle \\
\ (\text{cons } (\text{car } \text{numbers} \text{nonneg}) \text{neg}) \\
\ ((\langle \text{car } \text{numbers} \rangle \rangle) \\
\ (\text{loop } \langle \text{cdr } \text{numbers} \rangle \\
\ \text{nonneg})
\]

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### 4.2.5. Delayed evaluation

\[(\text{delay} \; \langle \text{expression} \rangle)\] lazy module syntax

The `delay` construct is used together with the procedure `force` to implement *lazy evaluation* or *call by need*. `delay \langle \text{expression} \rangle` returns an object called a *promise* which at some point in the future may be asked (by the `force` procedure) to evaluate \langle \text{expression} \rangle, and deliver the resulting value. The effect of \langle \text{expression} \rangle returning multiple values is unspecified.

See the description of `force` (section 6.4) for a more complete description of `delay`.

### 4.2.6. Dynamic Bindings

\[\text{(parameterize} \; ((\text{param value}) \ldots) \; \langle \text{expr}_1 \rangle \; \langle \text{expr}_2 \rangle \ldots)\] syntax

The value of the `param` expressions must be parameter objects. The `parameterize` form is used to change the values returned by parameter objects for the dynamic extent of the body. The expressions `param` and `converter value` are evaluated in an unspecified order. The `\langle \text{expr} \rangle`s are evaluated in order in a dynamic extent during which calls to the `param` parameter objects return the result of the corresponding `converter value`. The result(s) of the last `\langle \text{expr} \rangle` is(are) returned as the result(s) of the entire `parameterize` form.

If an implementation supports multiple threads of execution, then `parameterize` must not change the associated values of any parameters in any thread created before or after the call to `parameterize`.

See the description of `make-parameter` (section 6.4) for a more complete description of `parameterize`.

### 4.2.7. Exception Handling

\[\text{(guard} \; ((\text{variable}) \ldots) \; \langle \text{cond clause}_1 \rangle \; \langle \text{cond clause}_2 \rangle \ldots) \; \langle \text{body} \rangle)\] syntax

**Syntax:** Each `\langle \text{cond clause} \rangle` is as in the specification of `cond`.

**Semantics:** Evaluating a `guard` form evaluates `\langle \text{body} \rangle` with an exception handler that binds the raised object to `\langle \text{variable} \rangle` and within the scope of that binding evaluates the clauses as if they were the clauses of a `\langle \text{cond} \rangle` expression. That implicit `\langle \text{cond} \rangle` expression is evaluated with the continuation and dynamic extent of the `\langle \text{guard} \rangle` expression. If every `\langle \text{cond clause} \rangle`’s `\langle \text{test} \rangle` evaluates to *#f* and there is no `\langle \text{else} \rangle` clause, then *raise* is re-invoked on the raised object within the dynamic extent of the original call to *raise* except that the current exception handler is that of the `\langle \text{guard} \rangle` expression.

The final expression in a `\langle \text{cond} \rangle` clause is in a tail context if the `\langle \text{guard} \rangle` expression itself is.

See section 6.5 for a more complete discussion of exceptions.

### 4.2.8. Quasiquotation

\[(\text{quasiquote} \; \langle \text{qq template} \rangle)\] syntax

“Backquote” or “quasiquote” expressions are useful for constructing a list or vector structure when most but not all of the desired structure is known in advance. If no commas appear within the `\langle \text{qq template} \rangle`, the result of evaluating `\langle \text{qq template} \rangle` is equivalent to the result of evaluating `\langle \text{qq template} \rangle`. If a comma appears within the `\langle \text{qq template} \rangle`, however, the expression following the comma is evaluated (“unequoted”) and its result is inserted into the structure instead of the comma and the expression. If a comma appears followed immediately by an at-sign (`@`), then the following expression must evaluate to a list; the opening and closing parentheses of the list are then “stripped away” and the elements of the list are inserted in place of the comma at-sign expression sequence. A comma at-sign should only appear within a list or vector `\langle \text{qq template} \rangle`.

```
'(list ,(+ 1 2) 4) ⇒ (list 3 4)
(let ((name 'a)) '(list ,name ,name)) ⇒ (list a (quote a))
'(a ,(+ 1 2) ,@,(map abs ,(4 -5 6)) b) ⇒ (a 3 4 5 6 b)
'(( foo ,(10 3)) ,@(cdr '(c)) ,,(car '((cons)))
  )⇒ ((foo 7) . cons)
'#(10 5 ,(sqrt 4) ,(map sqrt '(16 9)) 8)⇒ #(10 5 2 4 3 8)
```

Quasiquote forms may be nested. Substitutions are made only for unquoted components appearing at the same nesting level as the outermost backquote. The nesting level increases by one inside each successive quasiquotation, and decreases by one inside each unquotation.

```
'(a `b ,(+ 1 2) ,(foo ,(+ 1 3) d) e) f) ⇒ (a `b ,(+ 1 2) ,(foo 4 d) e) f)
(let ((name1 'x)
  (name2 'y))
  '(a `b ,name1 ,',name2 d) e)) ⇒ (a `b ,x ,',y d) e)
```

The two notations `\langle \text{qq template} \rangle` and `\langle \text{quasiquote} \text{qq template} \rangle` are identical in all respects. `\langle \text{expression} \rangle`
is identical to (unquote (expression)), and \( \theta \) (expression) is identical to (unquote-splicing (expression)). The external syntax generated by write for two-element lists whose car is one of these symbols may vary between implementations.

\[
\text{quasiquote (list (unquote (+ 1 2)) 4)} \rightarrow \text{list 3 4}
\text{'(quasiquote (list (unquote (+ 1 2)) 4)) \rightarrow 'list ,(+ 1 2) 4}
\text{i.e., (quasiquote (list (unquote (+ 1 2)) 4))}
\]

Unpredictable behavior can result if any of the symbols quasiquote, unquote, or unquote-splicing appear in positions within a (qq template) otherwise than as described above.

### 4.2.9. Case-lambda

\[
\text{(case-lambda \{clause\_1 \{clause\_2\} ...\} \text{library syntax})}
\text{Syntax: Each (clause) should be of the form ((formals) (body)) where (formals) and (body) have the same syntax as in a lambda expression.}
\text{Semantics: A case-lambda expression evaluates to a procedure that accepts a variable number of arguments and is lexically scoped in the same manner as procedures resulting from a lambda expression. When the procedure is called, then the first (clause) for which the arguments agree with (formals) is selected, where agreement is specified as for the (formals) of a lambda expression. The variables of (formals) are bound to fresh locations, the values of the arguments are stored in those locations, the (body) is evaluated in the extended environment, and the results of (body) are returned as the results of the procedure call.}
\text{It is an error for the arguments not to agree with the (formals) of any (clause).}
\]

\[
\text{(define plus}
\begin{align*}
\text{(case-lambda}
&\begin{align*}
&((\cdot) 0) \\
&(\langle x \rangle x) \\
&(\langle x y \rangle (+ x y)) \\
&(\langle x y z \rangle (+ (+ x y) z)) \\
&(\text{args} (\text{apply} + \text{args})))
\end{align*}
\end{align*}\\
\begin{align*}
\text{)} \rightarrow 0 \\
\text{(plus 1)} \rightarrow 1 \\
\text{(plus 1 2 3)} \rightarrow 6
\end{align*}
\]

### 4.2.10. Reader Labels

\[
\#\langle n \rangle =\langle \text{datum} \rangle \quad \text{syntax}
\#\langle n \rangle \# \quad \text{syntax}
\]

\( N \) must be an unsigned decimal integer. The syntax \#\langle n \rangle =\langle \text{datum} \rangle reads as \langle \text{datum} \rangle, except that within the syntax of \langle \text{datum} \rangle the \langle \text{datum} \rangle is labelled by \langle n \rangle.

The syntax \#\langle n \rangle \# serves as a reference to some object labelled by \#\langle n \rangle =; the result is the same object as the \#\langle n \rangle = as compared with eqv? (see section 6.1). This permits notation of structures with shared or circular substructure.

\[
\begin{align*}
\text{(let ((x (list 'a 'b 'c)))} \\
&\text{(set-cdr! (caddr x))} \\
&\text{x}) \rightarrow \#0=(\langle a \, b \, c \rangle \#)
\end{align*}
\]

A reference \#\langle n \rangle \# may occur only after a label \#\langle n \rangle =; forward references are not permitted. In addition, the reference may not appear as the labelled object itself (that is, one may not write \#\langle n \rangle = \#\langle n \rangle \#), because the object labelled by \#\langle n \rangle = is not well defined in this case.

### 4.3. Macros

Scheme programs can define and use new derived expression types, called macros. Program-defined expression types have the syntax

\[
\langle \langle \text{keyword} \rangle \langle \text{datum} \rangle \ldots\rangle
\]

where \langle \text{keyword} \rangle is an identifier that uniquely determines the expression type. This identifier is called the syntactic keyword, or simply keyword, of the macro. The number of the \langle \text{datum} \rangle's, and their syntax, depends on the expression type.

Each instance of a macro is called a use of the macro. The set of rules that specifies how a use of a macro is transcribed into a more primitive expression is called the transformer of the macro.

The macro definition facility consists of two parts:

- A set of expressions used to establish that certain identifiers are macro keywords, associate them with macro transformers, and control the scope within which a macro is defined, and
- a pattern language for specifying macro transformers.

The syntactic keyword of a macro may shadow variable bindings, and local variable bindings may shadow keyword bindings. All macros defined using the pattern language are “hygienic” and “referentially transparent” and thus preserve Scheme’s lexical scoping [16, 17, 4, 9, 11]:

- If a macro transformer inserts a binding for an identifier (variable or keyword), the identifier will in effect be renamed throughout its scope to avoid conflicts with other identifiers. Note that a define at top level may or may not introduce a binding; see section 5.2.
- If a macro transformer inserts a free reference to an identifier, the reference refers to the binding that was visible where the transformer was specified, regardless of any local bindings that may surround the use of the macro.
4.3.1. Binding constructs for syntactic keywords

Let-syntax and letrec-syntax are analogous to let and letrec, but they bind syntactic keywords to macro transformers instead of binding variables to locations that contain values. Syntactic keywords may also be bound at top level; see section 5.3.

(let-syntax (bindings) (body))  syntax

Syntax: (Bindings) should have the form

(((keyword) (transformer spec) ...) ...)

Each (keyword) is an identifier, each (transformer spec) is an instance of syntax-rules, and (body) should be a sequence of one or more expressions. It is an error for a (keyword) to appear more than once in the list of keywords being bound.

Semantics: The (body) is expanded in the syntactic environment obtained by extending the syntactic environment of the let-syntax expression with macros whose keywords are the (keyword)s, bound to the specified transformers. Each binding of a (keyword) has (body) as its region.

(let-syntax (((when (syntax-rules ())
  ((when test stmt1 stmt2 ...) ...)
  (if test
    (begin stmt1 stmt2 ...))))

  (let (((if #t))
    (when if (set! if 'now))
    if))  \[\Rightarrow \text{now}\]

  (let ((x 'outer))
    (let-syntax (((m (syntax-rules ()) ((m) x)))
      (let ((x 'inner))
        (m)))  \[\Rightarrow \text{outer}\]

(letrec-syntax (bindings) (body))  syntax

Syntax: Same as for let-syntax.

Semantics: The (body) is expanded in the syntactic environment obtained by extending the syntactic environment of the letrec-syntax expression with macros whose keywords are the (keyword)s, bound to the specified transformers. Each binding of a (keyword) has the (bindings) as well as the (body) within its region, so the transformers can transcribe expressions into uses of the macros introduced by the letrec-syntax expression.

(letrec-syntax

  ((my-or (syntax-rules ())
    ((my-or) #f)
    ((my-or e) e)
    ((my-or el e2 ...) (let ((temp el))
      (if temp temp

4.3.2. Pattern language

A (transformer spec) has one of the following form:

(syntax-rules ((pattern) (template))...)

The (pattern) in a (syntax rule) is a list (pattern) whose first subform is an identifier or an underscore _.

A (pattern) is either an identifier, a constant, or one of the following

((pattern) ...)
((pattern) (pattern) ... (pattern))
((pattern) ... (pattern) (ellipsis) (pattern) ...)
((pattern) ... (pattern) (ellipsis) (pattern) ...
 . (pattern))
#((pattern) ...)
#((pattern) ... (pattern) (ellipsis) (pattern) ...)

and a template is either an identifier, a constant, or one of the following

((element) ...)
((element) (element) ... . (template))
((ellipsis) (element))
#((element) ...)

where an (element) is a (template) optionally followed by an (ellipsis). An (ellipsis) is the identifier specified in the second form of syntax-rules, or the default identifier ... (three consecutive periods) otherwise.

Semantics: An instance of syntax-rules produces a new macro transformer by specifying a sequence of hygienic rewrite rules. A use of a macro whose keyword is associated with a transformer specified by syntax-rules is matched against the patterns contained in the (syntax rule)s, beginning with the leftmost (syntax rule). When a match is found, the macro use is transcribed hygienically according to the template.
An identifier appearing within a ⟨pattern⟩ may be an underscore ("_"), a literal identifier listed in the list of (literal)s, or the ⟨ellipsis⟩. All other identifiers appearing within a ⟨pattern⟩ are pattern variables.

The keyword at the beginning of the pattern in a ⟨syntax rule⟩ is not involved in the matching and is not considered a pattern variable or literal identifier.

Pattern variables match arbitrary input elements and are used to refer to elements of the input in the template. It is an error for the same pattern variable to appear more than once in a ⟨pattern⟩.

Underscores also match arbitrary input subforms but are not pattern variables and so cannot be used to refer to those elements. If an underscore appears in the ⟨literal⟩s list, then that takes precedence and underscores in the ⟨pattern⟩ match as literals. Multiple underscores may appear in a ⟨pattern⟩.

Identifiers that appear in ⟨literal⟩ ... ⟨ellipsis⟩ are interpreted as literal identifiers to be matched against corresponding subforms of the input. A subform in the input matches a literal identifier if and only if it is an identifier and either both its occurrence in the macro expression and its occurrence in the macro definition have the same lexical binding, or the two identifiers are equal and both have no lexical binding.

A subpattern followed by ⟨ellipsis⟩ can match zero or more elements of the input, unless ⟨ellipsis⟩ appears in the ⟨literal⟩s in which case it is matched as a literal.

More formally, an input form \( F \) matches a pattern \( P \) if and only if:

- \( P \) is an underscore ("_").
- \( P \) is a non-literal identifier; or
- \( P \) is a list \((P_1 \ldots P_n)\) and \( F \) is a list of \( n \) forms that match \( P_1 \) through \( P_n \), respectively; or
- \( P \) is an improper list \((P_1 P_2 \ldots P_n \ldots P_n)\) and \( F \) is a list or improper list of \( n \) or more forms that match \( P_1 \) through \( P_n \), respectively, and whose \( n \)th "cdr" matches \( P_{n+1} \); or
- \( P \) is of the form \((P_1 \ldots P_{e-1} P_e ⟨ellipsis⟩ P_{m+1} \ldots P_n)\) where \( F \) is a proper list of \( n \) forms, the first \( e - 1 \) of which match \( P_1 \) through \( P_{e-1} \), respectively, whose next \( m - k \) forms each match \( P_e \), whose remaining \( n - m \) forms match \( P_{m+1} \) through \( P_n \), and whose \( n \)th and final cdr matches \( P_k \); or
- \( P \) is a vector of the form \#\((P_1 \ldots P_n)\) and \( F \) is a vector of \( n \) forms that match \( P_1 \) through \( P_n \); or
- \( P \) is of the form \#\((P_1 \ldots P_{e-1} P_e ⟨ellipsis⟩ P_{m+1} \ldots P_n)\) where \( F \) is a vector of \( n \) forms the first \( e - 1 \) of which match \( P_1 \) through \( P_{e-1} \), whose next \( m - k \) forms each match \( P_e \), and whose remaining \( n - m \) forms match \( P_{m+1} \) through \( P_n \); or
- \( P \) is a datum and \( F \) is equal to \( P \) in the sense of the equa? procedure.

It is an error to use a macro keyword, within the scope of its binding, in an expression that does not match any of the patterns.

When a macro use is transcribed according to the template of the matching ⟨syntax rule⟩, pattern variables that occur in the template are replaced by the subforms they match in the input. Pattern variables that occur in subpatterns followed by one or more instances of the identifier ⟨ellipsis⟩ are allowed only in subtemplates that are followed by as many instances of ⟨ellipsis⟩. They are replaced in the output by all of the subforms they match in the input, distributed as indicated. It is an error if the output cannot be built up as specified.

Identifiers that appear in the template but are not pattern variables or the identifier ⟨ellipsis⟩ are inserted into the output as literal identifiers. If a literal identifier is inserted as a free identifier then it refers to the binding of that identifier within whose scope the instance of ⟨syntax-rules⟩ appears. If a literal identifier is inserted as a bound identifier then it is in effect renamed to prevent inadvertent captures of free identifiers.

A template of the form ⟨⟨ellipsis⟩ ⟨template⟩⟩ is identical to ⟨template⟩, except that ellipses within the template have no special meaning. That is, any ellipses contained within ⟨template⟩ are treated as ordinary identifiers. In particular, the template ⟨⟨ellipsis⟩ ⟨ellipsis⟩⟩ produces a single ⟨ellipsis⟩. This allows syntactic abstractions to expand into forms containing ellipses.

\[
\text{(define-syntext be-like-begin}
\begin{align*}
\text{(syntax-rules (}) & \\
\text{(be-like-begin name)} & \\
\text{(define-syntext name}} & \\
\text{(syntax-rules (}) & \\
\text{(name expr (\ldots \ldots)))} & \\
\text{(begin expr \ldots \ldots)))}) & \\
\text{(be-like-begin sequence)} & \\
\text{(sequence 1 2 3 4) \mathbin{\Rightarrow} 4}
\end{align*}
\]

As an example, if \texttt{let} and \texttt{cond} are defined as in section 7.3 then they are hygienic (as required) and the following is not an error.
The macro transformer for `cond` recognizes `=>` as a local variable, and hence an expression, and not as the top-level identifier `=>`, which the macro transformer treats as a syntactic keyword. Thus the example expands into

```
(let ((=> #f))
  (if #t (begin => 'ok)))
```

instead of

```
(let ((=> #f))
  (let ((temp #t))
    (if temp ('ok temp))))
```

which would result in an invalid procedure call.

4.3.3. Signalling errors in macros

`(syntax-error ⟨message⟩ ⟨args⟩ ...) ...)` syntax

`syntax-error` is similar to `error` except that implementations with an expansion pass separate from evaluation should signal an error as soon as the `syntax-error` form is expanded. This can be used as a `syntax-rules` (template) for a ⟨pattern⟩ that is an invalid use of the macro, which can provide more descriptive error messages. ⟨message⟩ should be a string literal, and ⟨args⟩ arbitrary forms providing additional information.

```
(define-syntax simple-let
  (syntax-rules ()
    ((head ... ((x . y) val) . tail)
     body1 body2 ...)
    (syntax-error
     "expected an identifier but got" (x . y)))
    ((⟨(name val) ...⟩ body1 body2 ...)
     (lambda ⟨(name ...)⟩ body1 body2 ...)
     val ...))))
```

5. Program structure

5.1. Programs

A Scheme program consists of a sequence of program parts: expressions, definitions, syntax definitions, record-type definitions, imports, and includes. A collection of program parts may be encapsulated in a module to be reused by multiple programs. Expressions are described in chapter 4; the other program parts, as well as modules, are the subject of the rest of the present chapter.

Programs are typically stored in files or entered interactively to a running Scheme system, although other paradigms are possible; questions of user interface lie outside the scope of this report. (Indeed, Scheme would still be useful as a notation for expressing computational methods even in the absence of a mechanical implementation.)

Program parts other than expressions that are present at the top level of a program can be interpreted declaratively. They cause bindings to be created in the top level environment or modify the value of existing top-level bindings. Expressions occurring at the top level of a program are interpreted imperatively; they are executed in order when the program is invoked or loaded, and typically perform some kind of initialization.

At the top level of a program `(begin ⟨form1⟩ ...)` is equivalent to the sequence of expressions, definitions, and syntax definitions that form the body of the `begin`.

5.2. Definitions

Definitions are valid in some, but not all, contexts where expressions are allowed. They are valid only at the top level of a ⟨program⟩ and at the beginning of a ⟨body⟩.

A definition should have one of the following forms:

* `(define ⟨variable⟩ ⟨expression⟩)`

* `(define ⟨⟨variable⟩ ⟨formals⟩) ⟨body⟩)`

  ⟨Formals⟩ should be either a sequence of zero or more variables, or a sequence of one or more variables followed by a space-delimited period and another variable (as in a lambda expression). This form is equivalent to

  ```scheme
  (define ⟨variable⟩
    (lambda ⟨⟨formals⟩) ⟨body⟩)).
  ```

* `(define ⟨⟨variable⟩ . ⟨formal⟩) ⟨body⟩)`

  ⟨Formal⟩ should be a single variable. This form is equivalent to

  ```scheme
  (define ⟨variable⟩
    (lambda ⟨formal⟩ ⟨body⟩)).
  ```
5.2.1. Top level definitions

At the top level of a program, a definition

\[
\text{(define } \langle \text{variable} \rangle \ \langle \text{expression} \rangle \text{)}
\]

has essentially the same effect as the assignment expression

\[
\text{(set! } \langle \text{variable} \rangle \ \langle \text{expression} \rangle \text{)}
\]

if \(\langle \text{variable} \rangle\) is bound. If \(\langle \text{variable} \rangle\) is not bound, however, then the definition will bind \(\langle \text{variable} \rangle\) to a new location before performing the assignment, whereas it would be an error to perform a `set!` on an unbound variable.

\[
\text{(define add3 (lambda (x) (+ x 3)))}
\]

\[
\text{(add3 3)} \Rightarrow 6
\]

\[
\text{(define first car)}
\]

\[
\text{(first '(1 2))} \Rightarrow 1
\]

Some implementations of Scheme use an initial environment in which all possible variables are bound to locations, most of which contain undefined values. Top level definitions in such an implementation are truly equivalent to assignments.

5.2.2. Internal definitions

Definitions may occur at the beginning of a \(\langle \text{body} \rangle\) (that is, the body of a `lambda`, `let`, `let*`, `letrec`, `let-rec`, `let-syntax`, or `let-rec-syntax` expression or that of a definition of an appropriate form). Such definitions are known as internal definitions as opposed to the top level definitions described above. The variable defined by an internal definition is local to the \(\langle \text{body} \rangle\). That is, \(\langle \text{variable} \rangle\) is bound rather than assigned, and the region of the binding is the entire \(\langle \text{body} \rangle\). For example,

\[
\text{(let ((x 1) (y 2))}
\]

\[
\text{(define-syntax swap! (syntax-rules ()}
\]

\[
\text{((swap! a b) (let ((tmp a))}
\]

\[
\text{(set! a b) (set! b tmp))))) (swap! x y) (list x y))} \Rightarrow (2 1)
\]

Although macros may expand into definitions and syntax definitions in any context that permits them, it is an error for a definition or syntax definition to shadow a syntactic keyword whose meaning is needed to determine whether some form in the group of forms that contains the shadowing definition is in fact a definition, or, for internal definitions, is needed to determine the boundary between the group and the expressions that follow the group. For example, the following are errors:

\[
\text{(define define 3)}
\]

\[
\text{(begin (define begin list))}
\]

5.3. Syntax definitions

Syntax definitions are valid wherever definitions are. They have the following form:

\[
\text{(define-syntactix (keyword) (transformer spec))}
\]

(Keyword) is an identifier, and the (transformer spec) should be an instance of `syntax-rules`. If the `define-syntax` occurs at the top-level, then the top-level syntactic environment is extended by binding the (keyword) to the specified transformer. Otherwise, it is an internal syntax definition, and is local to the \(\langle \text{body} \rangle\) in which it is defined. Any internal syntax definitions in a body must come before any internal definitions.

\[
\text{(let ((x 1) (y 2))}
\]

\[
\text{(define-syntax swap! (syntax-rules ()}
\]

\[
\text{((swap! a b) (let ((tmp a))}
\]

\[
\text{(set! a b) (set! b tmp))))) (swap! x y) (list x y))} \Rightarrow (2 1)
\]

This section describes syntax for creating new data types, called record types. A predicate, constructor, and field accessors and modifiers are defined for each record type.
(define-record-type name constructor pred field ...) syntax

Syntax: ⟨name⟩ and ⟨pred⟩ should be identifiers. The ⟨constructor⟩ should be of the form

(⟨constructor name⟩ ⟨field name⟩ ...) and each ⟨field⟩ should be of the form

(⟨field name⟩ ⟨accessor name⟩)

| (⟨field name⟩ ⟨accessor name⟩ ⟨modifier name⟩)

define-record-type is generative: each use creates a new record type that is distinct from all existing types, including other record types and Scheme’s predefined types.

An instance of define-record-type is equivalent to the following definitions:

- ⟨name⟩ is bound to a representation of the record type itself, possibly as a syntactic form.
- ⟨constructor name⟩ is bound to a procedure that takes as many arguments as there are ⟨field name⟩/s in the ⟨constructor name⟩ ⟨field name⟩ subform and returns a new record of type ⟨name⟩. Fields whose names are listed with ⟨constructor name⟩ have the corresponding argument as their initial value. The initial values of all other fields are unspecified.
- ⟨pred⟩ is a predicate that returns #t when given a value returned by ⟨constructor name⟩ and #f for everything else.
- Each ⟨accessor name⟩ is a procedure that takes a record of type ⟨name⟩ and returns the current value of the corresponding field. It is an error to pass an accessor a value which is not a record of the appropriate type.
- Each ⟨modifier name⟩ is a procedure that takes a record of type ⟨name⟩ and a value which becomes the new value of the corresponding field; an unspecified value is returned. It is an error to pass a modifier a first argument which is not a record of the appropriate type.

The following

(define-record-type pare
  (kons x y)
  pare? (x kar set-kar!)
  (y kdr))

defines kons to be a constructor, kar and kdr to be accessors, set-kar! to be a modifier, and pare? to be a predicate for instances of pare.

5.5. Modules

Modules provide a way to encapsulate programs and manage the top-level namespace. This section defines the notation and semantics for modules.

5.5.1. Module Syntax

A module definition takes the following form:

(module ⟨module name⟩
  ⟨module declaration⟩ ...) ⟨module name⟩ is a list of identifiers or exact integers used to identify the module uniquely when importing from other programs or modules.

A ⟨module declaration⟩ can be any of:

- (export ⟨export spec⟩ ...) ⟨export spec⟩ must have one of the following forms:
  - (rename ⟨identifier1⟩ ⟨identifier2⟩)

In an ⟨export spec⟩, an ⟨identifier⟩ names a single binding defined within or imported into the library, where the external name for the export is the same as the name of the binding within the library. A rename spec exports the binding named by ⟨identifier1⟩ in each ⟨identifier1⟩ ⟨identifier2⟩ pairing, using ⟨identifier2⟩ as the external name.

An import declaration provides a way to import the identifiers exported by a module. Each ⟨import set⟩ names a set of bindings from another module and possibly specifies local names for the imported bindings. It must be one of the following:
5. Program structure

5.5.2. Module Examples

(module (stack)
  (export make push! pop! empty!)
  (import (scheme))
  (begin
    (define (make) (list ()))
    (define (push! s v)
      (set-car! s (cons v (car s))))
    (define (pop! s) (let ((v (caar s)))
      (set-car! s (cdr s))
      v))
    (define (empty! s) (set-car! s ())))

(module (balloons)
  (export make push pop)
  (import (scheme))
  (begin
    (define (make w h) (cons w h)))

The last clause may be an “else clause,” which has the form
(else (module declaration) ...)

A (feature requirement) must be one of the following forms:

- (feature identifier)
- (module (module name))
- (and (feature requirement) ...)
- (or (feature requirement) ...)
- (not (feature requirement))

Each implementation maintains a list of feature identifiers which are present, as well as a list of modules which can be imported. The value of a (feature requirement) can be determined by replacing each (feature identifier) and (module (module name)) on the implementation’s lists with #t, and all other feature identifiers and module names with #f, then evaluating the resulting expression as a Scheme boolean expression under the normal interpretation of and, or, and not.

A cond-expand form is then expanded by evaluating the (feature requirement)s of successive (cond-expand clause) in order, until one of them returns #t. When a true clause is found, the corresponding (module declaration)s are spliced into the current module definition and the remaining clauses are ignored. If none of the (feature requirement)s evaluate to #t, then if there is an else clause its (module declaration)s are included, otherwise the cond-expand has no effect.

The exact features provided are implementation-defined, but for portability a set of recommended features is given in appendix B.
(define (push b amt)
  (cons (- (car b) amt) (+ (cdr b) amt)))
(define (pop b)
  (display "Boom! ")
  (display (* (car b) (cdr b)))
  (newline)))

(module (party)
  ;; Total exports:
  ;; make, push, push!, make-party, pop!
  (export (rename (balloon:make make)
                  (bubble:push push))
            push!
            make-party
            (rename (party-pop! pop!)))

(import (scheme)
         (only (stack) make push! pop!)))) ; not empty!

(module (main)
  (export)
  (import (scheme) (party))
  (begin
    (define p (make-party))
    (pop! p) ; displays "Boom! 108"
    (push! p (push (make 5 5) 1))
    (pop! p))) ; displays "Boom! 24"

6. Standard procedures

This chapter describes Scheme's built-in procedures. The initial (or "top level") Scheme environment starts out with a number of variables bound to locations containing useful values, most of which are primitive procedures that manipulate data. For example, the variable abs is bound to (a location initially containing) a procedure of one argument that computes the absolute value of a number, and the variable + is bound to a procedure that computes sums.

A program may use a top-level definition to bind any variable. It may subsequently alter any such binding by an assignment (see 4.1.6). These operations do not modify the behavior of Scheme's built-in procedures. Altering any top-level binding that has not been introduced by a definition has an unspecified effect on the behavior of the built-in procedures.

6.1. Equivalence predicates

A predicate is a procedure that always returns a boolean value (#t or #f). An equivalence predicate is the computational analogue of a mathematical equivalence relation (it is symmetric, reflexive, and transitive). Of the equivalence predicates described in this section, eq? is the finest or most discriminating, and equal? is the coarsest. Eqv? is slightly less discriminating than eq?.

(eqv? obj1 obj2)

The eqv? procedure defines a useful equivalence relation on objects. Briefly, it returns #t if obj1 and obj2 should normally be regarded as the same object. This relation is left slightly open to interpretation, but the following partial specification of eqv? holds for all implementations of Scheme.

The eqv? procedure returns #t if:

- obj1 and obj2 are both #t or both #f.
- obj1 and obj2 are both symbols and
  (string? (symbol->string obj1))
  (string? (symbol->string obj2))
  =⇒ #t

Note: This assumes that neither obj1 nor obj2 is an “uninterned symbol” as alluded to in section 6.3.3. This report does not presume to specify the behavior of eqv? on implementation-dependent extensions.
- obj1 and obj2 are both numbers, are numerically equal (see =, section 6.2), and are either both exact or both inexact.
- obj1 and obj2 are both characters and are the same character according to the char=? procedure (section 6.3.4).
- both obj1 and obj2 are the empty list.
- obj1 and obj2 are pairs, vectors, or strings that denote the same locations in the store (section 3.4).
- obj1 and obj2 are procedures whose location tags are equal (section 4.1.4).

The eqv? procedure returns #f if:

- obj1 and obj2 are of different types (section 3.2).
- one of obj1 and obj2 is #t but the other is #f.
- obj1 and obj2 are symbols but
Affect the value or side effects of the procedures. obj1 and obj2 are numbers for which the = procedure returns #f.

obj1 and obj2 are characters for which the char=? procedure returns #f.

obj1 and obj2 are the empty list but the other is not.

obj1 and obj2 are pairs, vectors, or strings that denote distinct locations.

obj1 and obj2 are procedures that would behave differently (return different value(s) or have different side effects) for some arguments.

\[
\begin{align*}
\text{(eqv? 'a 'a)} & \iff \text{#t} \\
\text{(eqv? 'a 'b)} & \iff \text{#f} \\
\text{(eqv? 2 2)} & \iff \text{#t} \\
\text{(eqv? '() '())} & \iff \text{#t} \\
\text{(eqv? (cons 1 2) (cons 1 2))} & \iff \text{#f} \\
\text{(eqv? (lambda () 1) (lambda () 2))} & \iff \text{#f} \\
\text{(eqv? #f 'nil)} & \iff \text{#f} \\
\text{(let ((p (lambda (x) x))) (eqv? p p))} & \iff \text{#t}
\end{align*}
\]

The following examples illustrate cases in which the above rules do not fully specify the behavior of eqv?. All that can be said about such cases is that the value returned by eqv? must be a boolean.

\[
\begin{align*}
\text{(eqv? " " "')} & \iff \text{unspecified} \\
\text{(eqv? #() '#())} & \iff \text{unspecified} \\
\text{(eqv? (lambda (x) x) (lambda (x) x))} & \iff \text{unspecified} \\
\text{(eqv? (lambda (x) x) (lambda (y) y))} & \iff \text{unspecified}
\end{align*}
\]

The next set of examples shows the use of eqv? with procedures that have local state. Gen-counter must return a distinct procedure every time, since each procedure has its own internal counter. Gen-loser, however, returns equivalent procedures each time, since the local state does not affect the value or side effects of the procedures.

\[
\begin{align*}
\text{(define gen-counter}
\text{\quad \lambda (}
\text{\quad (let ((n 0))
\text{\quad (lambda () (set! n (+ n 1)) n))))
\text{\quad (let ((g (gen-counter)))
\text{\quad (eqv? g g))} \text{\quad \Rightarrow \text{#t}}
\text{\quad (eqv? (gen-counter) (gen-counter))})
\end{align*}
\]

6. Standard procedures

\[
\begin{align*}
\text{(define gen-loser}
\text{\quad \lambda (}
\text{\quad (let ((n 0))
\text{\quad (lambda () (set! n (+ n 1)) 27))))
\text{\quad (let ((g (gen-loser)))
\text{\quad (eqv? g g))} \text{\quad \Rightarrow \text{#t}}
\text{\quad (eqv? (gen-loser) (gen-loser)))} \text{\quad \Rightarrow \text{unspecified}}
\text{\quad (letrec ((f (lambda () (if (eqv? f g) 'both 'f)))
\text{\quad g (lambda () (if (eqv? f g) 'both 'g))))
\text{\quad (eqv? f g))} \text{\quad \Rightarrow \text{unspecified}}
\text{\quad (letrec ((f (lambda () (if (eqv? f g) 'f 'both)))
\text{\quad g (lambda () (if (eqv? f g) 'g 'both))))
\text{\quad (eqv? f g))} \text{\quad \Rightarrow \text{#f}}
\end{align*}
\]

Since it is an error to modify constant objects (those returned by literal expressions), implementations are permitted, though not required, to share structure between constants where appropriate. Thus the value of eqv? on constants is sometimes implementation-dependent.

\[
\begin{align*}
\text{(eqv? 'a 'a)} & \iff \text{unspecified} \\
\text{(eqv? "a" "a")} & \iff \text{unspecified} \\
\text{(eqv? '(a) '(a))} & \iff \text{unspecified} \\
\text{(eqv? (list 'a) (list 'a))} & \iff \text{unspecified} \\
\text{(let ((x 'a))) (eqv? x x)) \iff \text{#t}
\end{align*}
\]

**Rationale:** The above definition of eqv? allows implementations latitude in their treatment of procedures and literals: implementations are free either to detect or to fail to detect that two procedures or two literals are equivalent to each other, and can decide whether or not to merge representations of equivalent objects by using the same pointer or bit pattern to represent both.

\[
\begin{align*}
\text{(eq? obj1 obj2)} & \quad \text{procedure}
\end{align*}
\]

Eq? is similar to eqv? except that in some cases it is capable of discerning distinctions finer than those detectable by eqv?.

Eq? and eqv? are guaranteed to have the same behavior on symbols, booleans, the empty list, pairs, procedures, and non-empty strings and vectors. Eq?’s behavior on numbers and characters is implementation-dependent, but it will always return either true or false, and will return true only when eqv? would also return true. Eq? may also behave differently from eqv? on empty vectors and empty strings.

\[
\begin{align*}
\text{(eq? 'a 'a)} & \iff \text{#t} \\
\text{(eq? '(a) '(a))} & \iff \text{unspecified} \\
\text{(eq? #t #t)} & \iff \text{#f} \\
\text{(eq? "a" "a")} & \iff \text{unspecified} \\
\text{(eq? ** **)} & \iff \text{unspecified} \\
\text{(eq? () '())} & \iff \text{#t}
\end{align*}
\]
Rationale: It will usually be possible to implement \(\text{eq?}\) much more efficiently than \(\text{eqv?}\), for example, as a simple pointer comparison instead of as some more complicated operation. One reason is that it may not be possible to compute \(\text{eqv?}\) of two numbers in constant time, whereas \(\text{eq?}\) implemented as pointer comparison will always finish in constant time. \(\text{eq?}\) may be used like \(\text{eqv?}\) in applications using procedures to implement objects with state since it obeys the same constraints as \(\text{eqv?}\).

### 6.2. Numbers

Numerical computation has traditionally been neglected by the Lisp community. Until Common Lisp there was no carefully thought out strategy for organizing numerical computation, and with the exception of the MacLisp system [22] little effort was made to execute numerical code efficiently. This report recognizes the excellent work of the Common Lisp committee and accepts many of their recommendations. In some ways this report simplifies and generalizes their proposals in a manner consistent with the purposes of Scheme.

It is important to distinguish between the mathematical numbers, the Scheme numbers that attempt to model them, the machine representations used to implement the Scheme numbers, and notations used to write numbers. This report uses the types \textit{number}, \textit{complex}, \textit{real}, \textit{rational}, and \textit{integer} to refer to both mathematical numbers and Scheme numbers. Machine representations such as fixed point and floating point are referred to by names such as \texttt{fixnum} and \texttt{flonum}.

#### 6.2.1. Numerical types

Mathematically, numbers may be arranged into a tower of subtypes in which each level is a subset of the level above it:

- \textit{number}
- \textit{complex}
- \textit{real}
- \textit{rational}
- \textit{integer}

For example, 3 is an integer. Therefore 3 is also a rational, a real, and a complex. The same is true of the Scheme numbers that model 3. For Scheme numbers, these types are defined by the predicates \texttt{number?}, \texttt{complex?}, \texttt{real?}, \texttt{rational?}, and \texttt{integer?}.

There is no simple relationship between a number’s type and its representation inside a computer. Although most implementations of Scheme will offer at least two different representations of 3, these different representations denote the same integer.

Scheme’s numerical operations treat numbers as abstract data, as independent of their representation as possible. Although an implementation of Scheme may use \texttt{fixnum}, \texttt{flonum}, and perhaps other representations for numbers, this should not be apparent to a casual programmer writing simple programs.

It is necessary, however, to distinguish between numbers that are represented exactly and those that may not be. For example, indexes into data structures must be known exactly, as must some polynomial coefficients in a symbolic algebra system. On the other hand, the results of measurements are inherently inexact, and irrational numbers may be approximated by rational and therefore inexact approximations. In order to catch uses of inexact numbers where exact numbers are required, Scheme explicitly distinguishes exact from inexact numbers. This distinction is orthogonal to the dimension of type.

#### 6.2.2. Exactness

Scheme numbers are either \textit{exact} or \textit{inexact}. A number is exact if it was written as an exact constant or was derived from exact numbers using only exact operations. A number is inexact if it was written as an inexact constant, if it was derived using inexact ingredients, or if it was derived
using inexact operations. Thus inexactness is a contagious property of a number.

If two implementations produce exact results for a computation that did not involve inexact intermediate results, the two ultimate results will be mathematically equivalent. This is generally not true of computations involving inexact numbers since approximate methods such as floating point arithmetic may be used, but it is the duty of each implementation to make the result as close as practical to the mathematically ideal result.

Rational operations such as + should always produce exact results when given exact arguments. If the operation is unable to produce an exact result, then it may either report the violation of an implementation restriction or it may silently coerce its result to an inexact value. See section 6.2.3.

With the exception of inexact->exact, the operations described in this section must generally return inexact results when given any inexact arguments. An operation may, however, return an exact result if it can prove that the value of the result is unaffected by the inexactness of its arguments. For example, multiplication of any number by an exact zero may produce an exact zero result, even if the other argument is inexact.

6.2.3. Implementation restrictions

Implementations of Scheme are not required to implement the whole tower of subtypes given in section 6.2.1, but they must implement a coherent subset consistent with both the purposes of the implementation and the spirit of the Scheme language. For example, an implementation in which all numbers are real may still be quite useful.

Implementations may also support only a limited range of numbers of any type, subject to the requirements of this section. The supported range for exact numbers of any type may be different from the supported range for inexact numbers of that type. For example, an implementation that uses flonums to represent all its inexact real numbers may support a practically unbounded range of exact integers and rationals while limiting the range of inexact reals (and therefore the range of inexact integers and rationals) to the dynamic range of the flonum format. Furthermore the gaps between the representable inexact integers and rationals are likely to be very large in such an implementation as the limits of this range are approached.

An implementation of Scheme must support exact integers throughout the range of numbers that may be used for indexes of lists, vectors, and strings or that may result from computing the length of a list, vector, or string. The length, vector-length, and string-length procedures must return an exact integer, and it is an error to use anything but an exact integer as an index. Furthermore any integer constant within the index range, if expressed by an exact integer syntax, will indeed be read as an exact integer, regardless of any implementation restrictions that may apply outside this range. Finally, the procedures listed below will always return an exact integer result provided all their arguments are exact integers and the mathematically expected result is representable as an exact integer within the implementation:

- +
- -
- *
- quotient
- remainder
- modulo
- max
- min
- abs
- numerator
- denominator
- gcd
- lcm
- floor
- ceiling
- truncate
- round
- rationalize
- expt

Implementations are encouraged, but not required, to support exact integers and exact rationals of practically unlimited size and precision, and to implement the above procedures and the / procedure in such a way that they always return exact results when given exact arguments. If one of these procedures is unable to deliver an exact result when given exact arguments, then it may either report a violation of an implementation restriction or it may silently coerce its result to an inexact number. Such a coercion may cause an error later.

An implementation may use floating point and other approximate representation strategies for inexact numbers. This report recommends, but does not require, that the IEEE 754 standard be followed by implementations that use flonum representations, and that implementations using other representations should match or exceed the precision achievable using these floating point standards [14].

In particular, implementations that use flonum representations must follow these rules: A flonum result must be represented with at least as much precision as is used to express any of the inexact arguments to that operation. It is desirable (but not required) for potentially inexact operations such as sqrt, when applied to exact arguments, to produce exact answers whenever possible (for example the square root of an exact 4 should be an exact 2). If, however, an exact number is operated upon so as to produce an inexact result (as by sqrt), and if the result is represented as a flonum, then the most precise flonum format available must be used; but if the result is represented in some other way then the representation must have at least as much precision as the most precise flonum format available.

In addition, implementations that use flonum representations may distinguish special number objects called positive infinity, negative infinity, and NaN.

Positive infinity is regarded as an inexact real (but not rational) number object that represents an indeterminate number greater than the numbers represented by all rational number objects. Negative infinity is regarded as an
inexact real (but not rational) number object that represents an indeterminate number less than the numbers represented by all rational numbers.

A NaN is regarded as an inexact real (but not rational) number object so indeterminate that it might represent any real number, including positive or negative infinity, and might even be greater than positive infinity or less than negative infinity. It might even represent no number at all, as in the case of (asin 2.0).

Although Scheme allows a variety of written notations for numbers, any particular implementation may support only some of them. For example, an implementation in which all numbers are real need not support the rectangular and polar notations for complex numbers. If an implementation encounters an exact numerical constant that it cannot represent as an exact number, then it may either report a violation of an implementation restriction or it may silently represent the constant by an inexact number.

6.2.4. Syntax of numerical constants

The syntax of the written representations for numbers is described formally in section 7.1.1. Note that case is not significant in numerical constants.

A number may be written in binary, octal, decimal, or hexadecimal by the use of a radix prefix. The radix prefixes are #b (binary), #o (octal), #d (decimal), and #x (hexadecimal). With no radix prefix, a number is assumed to be expressed in decimal.

A numerical constant may be specified to be either exact or inexact by a prefix. The prefixes are #e for exact, and #i for inexact. An exactness prefix may appear before or after any radix prefix that is used. If the written representation of a number has no exactness prefix, the constant may be either inexact or exact. It is inexact if it contains a decimal point, an exponent, or a “#” character in the place of a digit, otherwise it is exact.

In systems with inexact numbers of varying precisions it may be useful to specify the precision of a constant. For this purpose, implementations may accept numerical constants written with an exponent marker that indicates the desired precision of the inexact representation. The letters s, f, d, and l, meaning short, single, double, and long precision respectively, are acceptable in place of e. The default precision has at least as much precision as double, but implementations may wish to allow this default to be set by the user.

```
3.14159265358979F0  Round to single — 3.141593
0.6L0               Extend to long — .600000000000000
```

The numbers positive infinity, negative infinity and NaN are written +inf.0, -inf.0 and +nan.0 respectively.

6.2.5. Numerical operations

The reader is referred to section 1.3.3 for a summary of the naming conventions used to specify restrictions on the types of arguments to numerical routines. The examples used in this section assume that any numerical constant written using an exact notation is indeed represented as an exact number. Some examples also assume that certain numerical constants written using an inexact notation can be represented without loss of accuracy; the inexact constants were chosen so that this is likely to be true in implementations that use flonums to represent inexact numbers.

```
(number? obj) procedure
(complex? obj) procedure
(real? obj) procedure
(rational? obj) procedure
(integer? obj) procedure
```

These numerical type predicates can be applied to any kind of argument, including non-numbers. They return #t if the object is of the named type, and otherwise they return #f.

In general, if a type predicate is true of a number then all higher type predicates are also true of that number. Consequently, if a type predicate is false of a number, then all lower type predicates are also false of that number.

If z is an inexact complex number, then (real? z) is true if and only if (zero? (imag-part z)) is true. If x is an inexact real number, then (integer? x) is true if and only if (= x (round x)).

```
(complex? 3+4i) ⇒ #t
(complex? 3) ⇒ #t
(real? 3) ⇒ #t
(real? -2.5+0.0i) ⇒ #t
(real? #e1e10) ⇒ #t
(rational? 6/10) ⇒ #t
(rational? 6/3) ⇒ #t
(integer? 3+0i) ⇒ #t
(integer? 3.0) ⇒ #t
(integer? 8/4) ⇒ #t
```

Note: The behavior of these type predicates on inexact numbers is unreliable, since any inaccuracy may affect the result.

Note: In many implementations the complex? procedure will be the same as number?, but unusual implementations may be able to represent some irrational numbers exactly or may extend the number system to support some kind of non-complex numbers.

```
(exact? z) procedure
(inexact? z) procedure
```

These numerical predicates provide tests for the exactness of a quantity. For any Scheme number, precisely one of these predicates is true.
(exact? 3.0)  =>  #f
(exact? #e3.0)  =>  #t
(inexact? 3.)  =>  #t

Note: If any argument is inexact, then the result will also be inexact (unless the procedure can prove that the inaccuracy is not large enough to affect the result, which is possible only in unusual implementations). If \text{min} \text{ or} \text{max} is used to compare numbers of mixed exactness, and the numerical value of the result cannot be represented as an inexact number without loss of accuracy, then the procedure may report a violation of an implementation restriction.

(zero? z)

The conjunction of exact? and integer?, returns #t iff z is both exact and an integer.

(finite? z)

These numerical predicates provide tests for the infinite and NaN numbers. For any Scheme number, precisely one of these predicates is true.

(finite? 3)  =>  #t
(finite? +inf.0)  =>  #f

(nan? z)

These procedures return the sum or product of their arguments.

(+ z1 ...)  procedure
(* z1 ...)  procedure

These procedures return #t if their arguments are (respectively): equal, monotonically increasing, monotonically decreasing, monotonically nondecreasing, or monotonically nonincreasing.

Note: The traditional implementations of these predicates in Lisp-like languages are not transitive.

Note: While it is not an error to compare inexact numbers using these predicates, the results may be unreliable because a small inaccuracy may affect the result; this is especially true of = and zero?. When in doubt, consult a numerical analyst.

(zero? z)

These numerical predicates test a number for a particular property, returning #t or #f. See note above.

(floor/ n1 n2)
(floor-quotient n1 n2)
(floor-remainder n1 n2)
(ceiling/ n1 n2)
(ceiling-quotient n1 n2)
(ceiling-remainder n1 n2)
(truncate/ n1 n2)
(truncate-quotient n1 n2)
(truncate-remainder n1 n2)
There are three procedures defined as follows:

1. **(round/ n₁ n₂)** procedure
2. **(round-quotient n₁ n₂)** procedure
3. **(round-remainder n₁ n₂)** procedure
4. **(euclidean/ n₁ n₂)** procedure
5. **(euclidean-quotient n₁ n₂)** procedure
6. **(euclidean-remainder n₁ n₂)** procedure

These procedures, all in the division module, implement number-theoretic (integer) division. \( n₂ \) should be non-zero. All fifteen procedures return integers. The procedures compute a quotient \( q \) and remainder \( r \) such that \( n₁ = n₂q + r \). For each of the five division operators, there are three procedures defined as follows:

- **(operator)/** procedure
- **(operator)-quotient** procedure
- **(operator)-remainder** procedure

The remainder \( r \) is determined by the choice of integer \( n_q \): \( n_r = n₁ - n₂n_q \). Each set of operators uses a different choice of \( n_q \):

- **ceiling** \( n_q = \lceil n₁/n₂ \rceil \)
- **floor** \( n_q = \lfloor n₁/n₂ \rfloor \)
- **truncate** \( n_q = \text{truncate}(n₁/n₂) \)
- **round** \( n_q = \lfloor n₁/n₂ \rfloor \)
- **euclidean** if \( n₂ > 0, n_q = \lceil n₁/n₂ \rceil \); if \( n₂ < 0, n_q = \lfloor n₁/n₂ \rfloor \)

For any of the operators, and for integers \( n₁ \) and \( n₂ \) with \( n₂ \) not equal to 0,

\[
(= n₁ (+ (* n₂ ((operator)-quotient n₁ n₂))) ((operator)-remainder n₁ n₂))) \Rightarrow #t
\]

provided all numbers involved in that computation are exact.

The procedures return integers. **Floor** returns the largest integer not larger than \( x \). **Ceiling** returns the smallest integer not smaller than \( x \). **Truncate** returns the integer closest to \( x \) whose absolute value is not larger than the absolute value of \( x \). **Round** returns the closest integer to \( x \), rounding to even when \( x \) is halfway between two integers.

**Rationale:** Round rounds to even for consistency with the default rounding mode specified by the IEEE floating point standard.

**Note:** If the argument to one of these procedures is inexact, then the result will also be inexact. If an exact value is needed, the result should be passed to the **exact->inexact** procedure.

\[
\begin{align*}
\text{(gcd } n₁ \ldots \text{)} & \Rightarrow 4 \\
\text{(lcm } n₁ \ldots \text{)} & \Rightarrow 0 \\
\text{(gcd) } & \Rightarrow 4 \\
\text{(lcm } 32 \ldots \text{)} & \Rightarrow 288 \\
\text{(lcm } 32.0 \ldots \text{)} & \Rightarrow 288.0 ; \text{ inexact} \\
\text{(lcm) } & \Rightarrow 1 \\
\text{(numerator } q \text{)} & \Rightarrow \text{ procedure} \\
\text{(denominator } q \text{)} & \Rightarrow \text{ procedure} \\
\text{(floor } x \text{)} & \Rightarrow \text{ procedure} \\
\text{(ceiling } x \text{)} & \Rightarrow \text{ procedure} \\
\text{(truncate } x \text{)} & \Rightarrow \text{ procedure} \\
\text{(round } x \text{)} & \Rightarrow \text{ procedure} \\
\end{align*}
\]

These procedures return the greatest common divisor or least common multiple of their arguments. The result is always non-negative.
(rationalize $x \ y$) procedure

Rationalize returns the simplest rational number differing from $x$ by no more than $y$. A rational number $r_1$ is simpler than another rational number $r_2$ if $r_1 = p_1/q_1$ and $r_2 = p_2/q_2$ (in lowest terms) and $|p_1| \leq |p_2|$ and $|q_1| \leq |q_2|$. Thus $3/5$ is simpler than $4/7$. Although not all rationals are comparable in this ordering (consider $2/7$ and $3/5$) any interval contains a rational number that is simpler than every other rational number in that interval (the simpler $2/5$ lies between $2/7$ and $3/5$). Note that $0 = 0/1$ is the simplest rational of all.

\[
\begin{align*}
\text{(rationalize} \ 1/3/10) & \quad \mapsto 1/3 \quad ; \text{exact} \\
\text{(rationalize} .3 \ 1/10 & \quad \mapsto \text{#i}1/3 \quad ; \text{inexact}
\end{align*}
\]

These procedures compute the usual transcendental functions. Log computes the natural logarithm of $z$ (not the base ten logarithm). Asin, acos, and atan compute arcsine ($\sin^{-1}$), arccosine ($\cos^{-1}$), and arctangent ($\tan^{-1}$), respectively. The two-argument variant of atan computes (angle (make-rectangular $x \ y$)) (see below), even in implementations that don’t support general complex numbers.

In general, the mathematical functions log, arcsine, arccosine, and arctangent are multiply defined. The value of log $z$ is defined to be the one whose imaginary part lies in the range from $-\pi$ (exclusive) to $\pi$ (inclusive). log 0 is undefined. With log defined this way, the values of $\sin^{-1}z$, $\cos^{-1}z$, and $\tan^{-1}z$ are according to the following formulas:

\[
\begin{align*}
\sin^{-1}z & = -i \log(iz + \sqrt{1 - z^2}) \\
\cos^{-1}z & = \pi/2 - \sin^{-1}z \\
\tan^{-1}z & = (\log(1 + iz) - \log(1 - iz)) / (2i)
\end{align*}
\]

The above specification follows [29], which in turn cites [21]; refer to these sources for more detailed discussion of branch cuts, boundary conditions, and implementation of these functions. When it is possible these procedures produce a real result from a real argument.

(sqrt $z$) inexact module procedure

Returns the principal square root of $z$. The result will have either positive real part, or zero real part and non-negative imaginary part.

(exact-integer-sqrt $k$) procedure

Returns two non-negative exact integer objects $s$ and $r$ where $k = s^2 + r$ and $k < (s + 1)^2$.

\[
\begin{align*}
\text{(exact-integer-sqrt} \ 4 & \quad \mapsto 2 \ 0 \\
\text{(exact-integer-sqrt} \ 5 & \quad \mapsto 2 \ 1
\end{align*}
\]

(expt $z_1 \ z_2$) procedure

Returns $z_1$ raised to the power $z_2$. For $z_1 \neq 0$

\[
z_1^{z_2} = e^{z_2 \log z_1}
\]

0$^2$ is 1 if $z = 0$ and 0 otherwise.

(make-rectangular $x_1 \ x_2$) complex module procedure

(make-polar $x_3 \ x_4$) complex module procedure

(real-part $z$) complex module procedure

(imag-part $z$) complex module procedure

(magnitude $z$) complex module procedure

(angle $z$) complex module procedure

Suppose $x_1$, $x_2$, $x_3$, and $x_4$ are real numbers and $z$ is a complex number such that

\[
z = x_1 + x_2 i = x_3 - e^{i x_4}
\]

Then

\[
\begin{align*}
\text{(make-rectangular} \ x_1 \ x_2 & \quad \mapsto z \\
\text{(make-polar} \ x_3 \ x_4 & \quad \mapsto z \\
\text{(real-part} \ z & \quad \mapsto x_1 \\
\text{(imag-part} \ z & \quad \mapsto x_2 \\
\text{(magnitude} \ z & \quad \mapsto |x_3| \\
\text{(angle} \ z & \quad \mapsto x_4
\end{align*}
\]

where $-\pi < x_{angle} \leq \pi$ with $x_{angle} = x_4 + 2\pi n$ for some integer $n$.

Rational: Magnitude is the same as abs for a real argument, but abs is in the base module, whereas magnitude is in the optional complex module.

(exact->inexact $z$) procedure

(inexact->exact $z$) procedure

Exact->inexact returns an inexact representation of $z$. The value returned is the inexact number that is numerically closest to the argument. If an exact argument has no reasonably close inexact equivalent, then a violation of an implementation restriction may be reported.

Inexact->exact returns an exact representation of $z$. The value returned is the exact number that is numerically closest to the argument. If an inexact argument has no reasonably close exact equivalent, then a violation of an implementation restriction may be reported.

These procedures implement the natural one-to-one correspondence between exact and inexact integers throughout an implementation-dependent range. See section 6.2.3.
6.2.6. Numerical input and output

(number->string z)  procedure
(number->string z radix)  procedure

Radix must be an exact integer, either 2, 8, 10, or 16. If omitted, radix defaults to 10. The procedure number->string takes a number and a radix and returns as a string an external representation of the given number in the given radix such that

(let ((number
    (radix radix))
  (eqv? number
    (string->number (number->string number
                     radix)
                     radix)))

is true. It is an error if no possible result makes this expression true.

If z is inexact, the radix is 10, and the above expression can be satisfied by a result that contains a decimal point, then the result contains a decimal point and is expressed using the minimum number of digits (exclusive of exponent and trailing zeroes) needed to make the above expression true [5, 7]; otherwise the format of the result is unspecified.

The result returned by number->string never contains an explicit radix prefix.

Note: The error case can occur only when z is not a complex number or is a complex number with a non-rational real or imaginary part.

Rationale: If z is an inexact number represented using flonums, and the radix is 10, then the above expression is normally satisfied by a result containing a decimal point. The unspecified case allows for infinities, NaNs, and non-flonum representations.

(string->number string)  procedure
(string->number string radix)  procedure

Returns a number of the maximally precise representation expressed by the given string. Radix must be an exact integer, either 2, 8, 10, or 16. If supplied, radix is a default radix that may be overridden by an explicit radix prefix in string (e.g., "#o177"). If radix is not supplied, then the default radix is 10. If string is not a syntactically valid notation for a number, then string->number returns #f.

(string->number "100")  ⇒  100
(string->number "100 16")  ⇒  256
(string->number "1e2")  ⇒  100.0
(string->number "15##")  ⇒  1500.0

Note: The domain of string->number may be restricted by implementations in the following ways. String->number is permitted to return #f whenever string contains an explicit radix prefix. If all numbers supported by an implementation are real, then string->number is permitted to return #f whenever string uses the polar or rectangular notations for complex numbers. If all numbers are integers, then string->number may return #f whenever the fractional notation is used. If all numbers are exact, then string->number may return #f whenever an exponent marker or explicit exactness prefix is used, or if a # appears in place of a digit. If all inexact numbers are integers, then string->number may return #f whenever a decimal point is used.

6.3. Other data types

This section describes operations on some of Scheme’s non-numeric data types: booleans, pairs, lists, symbols, characters, strings and vectors.

6.3.1. Booleans

The standard boolean objects for true and false are written as #t and #f. What really matters, though, are the objects that the Scheme conditional expressions (if, cond, and, or, do) treat as true or false. The phrase “a true value” (or sometimes just “true”) means any object treated as true by the conditional expressions, and the phrase “a false value” (or “false”) means any object treated as false by the conditional expressions.

Of all the standard Scheme values, only #f counts as false in conditional expressions. Except for #f, all standard Scheme values, including #t, pairs, the empty list, symbols, numbers, strings, vectors, and procedures, count as true.

Note: Programmers accustomed to other dialects of Lisp should be aware that Scheme distinguishes both #f and the empty list from the symbol nil.

Boolean constants evaluate to themselves, so they do not need to be quoted in programs.

#t  ⇒  #t
#f  ⇒  #f
' #f  ⇒  #f

(not obj)  procedure

Not returns #t if obj is false, and returns #f otherwise.

(not #t)  ⇒  #f
(not 3)  ⇒  #f
(not (list 3))  ⇒  #f
(not #f)  ⇒  #t
(not '(()))  ⇒  #f
(not (list))  ⇒  #f
(not 'nil)  ⇒  #f

#t  ⇒  #t
#f  ⇒  #f
6. Standard procedures

Pairs are created by the procedure with two fields called the car and cdr fields (for historical reasons). Pairs are used primarily to represent lists. A list can be defined as either the empty list or a pair whose car is the second element and whose cdr is a list. More precisely, the set of lists is defined recursively as:

\[
\text{list} \quad \text{is also a list}\.
\]

Pairs are created by the procedure `cons`. The car and cdr fields are assigned by the procedures `set-car!` and `set-cdr!`.

Pairs are used primarily to represent lists. A list can be defined recursively as either the empty list or a pair whose cdr field contains a list. More precisely, the set of lists is defined as the smallest set \( X \) such that:

- The empty list is in \( X \).
- If \( \text{list} \) is in \( X \), then any pair whose cdr field contains \( \text{list} \) is also in \( X \).

The objects in the car fields of successive pairs of a list are the elements of the list. For example, a two-element list whose car is the first element and whose cdr is a pair whose car is the second element and whose cdr is the empty list. The length of a list is the number of elements, which is the same as the number of pairs.

The empty list is a special object of its own type (it is not a pair); it has no elements and its length is zero.

**Note:** The above definitions imply that all lists have finite length and are terminated by the empty list.

The most general notation (external representation) for Scheme pairs is the “dotted” notation \((c_1 . c_2)\) where \(c_1\) is the value of the car field and \(c_2\) is the value of the cdr field. For example \((4 . 5)\) is a pair whose car is 4 and whose cdr is 5. Note that \((4 . 5)\) is the external representation of a pair, not an expression that evaluates to a pair.

A more streamlined notation can be used for lists: the elements of the list are simply enclosed in parentheses and separated by spaces. The empty list is written \(()\). For example,

\[
(a \ b \ c \ d \ e)
\]

and

\[
(a \ (b \ (c \ (d \ (e \ ()))))
\]

are equivalent notations for a list of symbols.

A chain of pairs not ending in the empty list is called an improper list. Note that an improper list is not a list.

The list and dotted notations can be combined to represent improper lists:

\[
(a \ b \ c \ . \ d)
\]

is equivalent to

\[
(a \ . \ (b \ . \ (c \ . \ d)))
\]

Whether a given pair is a list depends upon what is stored in the cdr field. When the `set-cdr!` procedure is used, an object can be a list one moment and not the next:

\[
\text{(define } x \ \text{(list } 'a \ 'b \ 'c))
\]

\[
\text{(define } y \ x)
\]

\[
\text{y} \quad \Rightarrow \quad (a \ b \ c)
\]

\[
\text{(list? } y)\quad \Rightarrow \quad \#t
\]

\[
\text{(set-cdr! } x \ 4)\quad \Rightarrow \quad \text{unspecified}
\]

\[
\text{x} \quad \Rightarrow \quad (a \ . \ 4)
\]

\[
\text{(eqv? } x \ y)\quad \Rightarrow \quad \#t
\]

\[
\text{y} \quad \Rightarrow \quad (a \ . \ 4)
\]

\[
\text{(list? } y)\quad \Rightarrow \quad \#f
\]

\[
\text{(set-cdr! } x \ x)\quad \Rightarrow \quad \text{unspecified}
\]

\[
\text{(list? } x)\quad \Rightarrow \quad \#f
\]

Within literal expressions and representations of objects read by the `read` procedure, the forms `'(datum), `'(datum), `'(datum), and `'(datum) denote two-element lists whose first elements are the symbols `quot`, `quasiquote`, `unquote`, and `unquote-splicing`, respectively. This convention is supported so that arbitrary Scheme programs may be represented as lists. That is, according to Scheme's grammar, every `expression` is also a `datum` (see section 7.1.2). Among other things, this permits the use of the `read` procedure to parse Scheme programs. See section 3.3.

**Procedure**: `pair? obj`  
**Returns**: \#t if \( \text{obj} \) is a pair, and otherwise returns \#f.

\[
\text{(pair? } '(a \ . \ b)) \quad \Rightarrow \quad \#t
\]

\[
\text{(pair? } '(a \ b \ c)) \quad \Rightarrow \quad \#t
\]

\[
\text{(pair? } '()) \quad \Rightarrow \quad \#f
\]

\[
\text{(pair? } 'a \ b) \quad \Rightarrow \quad \#f
\]

**Procedure**: `cons obj1 obj2`  
**Returns**: a newly allocated pair whose car is \( \text{obj1} \) and whose cdr is \( \text{obj2} \). The pair is guaranteed to be different (in the sense of `eqv?`) from every existing object.

\[
\text{(cons } 'a \ ()) \quad \Rightarrow \quad (a)
\]

\[
\text{(cons } '(a) \ '(b \ c \ d)) \quad \Rightarrow \quad ((a) \ b \ c \ d)
\]

\[
\text{(cons } "a" \ '(b \ c)) \quad \Rightarrow \quad ("a" \ b \ c)
\]

\[
\text{(cons } 'a \ 3) \quad \Rightarrow \quad (a \ . \ 3)
\]

\[
\text{(cons } '(a \ b) \ 'c) \quad \Rightarrow \quad ((a) \ b) \ . \ c)
\]
(car pair)  procedure

Returns the contents of the car field of pair. Note that it is an error to take the car of the empty list.

(car '((a) b c d))  ⇒  (a)
(car '())  ⇒  error

(cdr pair)  procedure

Returns the contents of the cdr field of pair. Note that it is an error to take the cdr of the empty list.

(cdr '())  ⇒  error

(set-car! pair obj)  procedure

Stores obj in the car field of pair. The value returned by set-car! is unspecified.

(set-car! (f) 3)  ⇒  unspecified
(set-car! (g) 3)  ⇒  error

(set-cdr! pair obj)  procedure

Stores obj in the cdr field of pair. The value returned by set-cdr! is unspecified.

(set-cdr! (f) 3)  ⇒  unspecified
(set-cdr! (g) 3)  ⇒  error

These procedures are compositions of car and cdr, where for example caddr could be defined by

(define caddr (lambda (x) (car (cdr (cdr x))))).

Arbitrary compositions, up to four deep, are provided. There are twenty-eight of these procedures in all.

(null? obj)  procedure

Returns #t if obj is the empty list, otherwise returns #f.

(list? obj)  procedure

Returns #t if obj is a list, otherwise returns #f. By definition, all lists have finite length and are terminated by the empty list.

(make-list k)  procedure

Returns a newly allocated list of k elements. If a second argument is given, then each element is initialized to fill. Otherwise the initial contents of each element is unspecified.

(list obj ...)  procedure

Returns a newly allocated list of its arguments.

(length list)  procedure

Returns the length of list.

(reverse list)  procedure

Returns a newly allocated list consisting of the elements of the first list followed by the elements of the other lists.

(list-tail list k)  procedure

Returns the sublist of list obtained by omitting the first k elements. It is an error if list has fewer than k elements. List-tail could be defined by
(define list-tail)
  (lambda (x k)
    (if (zero? k)
        x
        (list-tail (cdr x) (- k 1)))))

(list-ref list k)  procedure

Returns the kth element of list. (This is the same as the
car of (list-tail list k).) It is an error if list has fewer
than k elements.

(list-ref '(a b c d) 2)  \rightarrow  c
(list-ref '(a b c d)
  (inexact->exact (round 1.8)))  \rightarrow  c

(list-set! list k obj)  procedure

k must be a valid index of list. List-set! stores obj in
element k of list. The value returned by list-set! is
unspecified.

(let ((list (list 0 '(2 2 2) "Anna")))
  (list-set! lst 1 "Sue" "Sue")
  vec)
  \rightarrow  (0 "Sue" "Sue" "Anna")

(list-set! '(0 1 2) 1 "doo")
  \rightarrow  error ); constant list

(memq obj list)  procedure
(memv obj list)  procedure
(member obj list)  procedure
(member obj list compare)  procedure

These procedures return the first sublist of list whose car
is obj, where the sublists of list are the non-empty lists
returned by (list-tail list k) for k less than the length of
list. If obj does not occur in list, then #f (not the empty
list) is returned. Memq uses eq? to compare obj with the
elements of list, while memv uses eqv? and member uses
compare if given and equal? otherwise.

(memq 'a '(a b c))  \rightarrow  (a b c)
(memq 'b '(a b c))  \rightarrow  (b c)
(memq 'a '(b c d))  \rightarrow  #f
(memq (list 'a) '(b (a) c))  \rightarrow  #f
(member (list 'a)
  '(b (a) c))  \rightarrow  ((a) c)
(member "B"
  ("a" "b" "c")
  string-ci?)  \rightarrow  ("b" "c")
(memq 101 '((100 101 102))  \rightarrow  unspecified
(memv 101 '((100 101 102))  \rightarrow  (101 102)

(assq obj alist)  procedure
(assv obj alist)  procedure
(assoc obj alist)  procedure
(assoc obj alist compare)  procedure

Alist (for "association list") must be a list of pairs. These
procedures find the first pair in alist whose car field is obj,
and returns that pair. If no pair in alist has obj as its
car, then #f (not the empty list) is returned. Assq uses
eq? to compare obj with the car fields of the pairs in alist,
while assv uses eqv? and assoc uses compare if given and
equal? otherwise.

(define e '((a 1) (b 2) (c 3)))
(assq 'a e)  \rightarrow  (a 1)
(assq 'b e)  \rightarrow  (b 2)
(assq 'd e)  \rightarrow  #f
(assq (list 'a) '(((a)) ((b)) ((c))))
  \rightarrow  #f
(assoc (list 'a) '(((a)) ((b)) ((c))))
  \rightarrow  ((a))
(assq 5 '((2 3) (5 7) (11 13)))
  \rightarrow  unspecified
(assv 5 '((2 3) (5 7) (11 13)))
  \rightarrow  (5 7)

Rationale: Although they are ordinarily used as predicates,
memq, memv, member, assq, assv, and assoc do not have question
marks in their names because they return useful values rather
than just #t or #f.

(list-copy list)  procedure

Returns a newly allocated copy of the given list.

6.3.3. Symbols

Symbols are objects whose usefulness rests on the fact that
two symbols are identical (in the sense of eqv?) if and only
if their names are spelled the same way. This is exactly the
property needed to represent identifiers in programs, and
so most implementations of Scheme use them internally for
that purpose. Symbols are useful for many other applica-
tions; for instance, they may be used the way enumerated
values are used in Pascal.

The rules for writing a symbol are exactly the same as the
rules for writing an identifier; see sections 2.1 and 7.1.1.

It is guaranteed that any symbol that has been returned
as part of a literal expression, or read using the read
procedure, and subsequently written out using the write
procedure, will read back in as the identical symbol (in the
sense of eqv?).

Note: Some implementations have values known as "unin-
terred symbols", which defeat write/read invariance, and also
generate exceptions to the rule that two symbols are the same
if and only if their names are spelled the same.
(symbol? obj) procedure

Returns #t if obj is a symbol, otherwise returns #f.

- (symbol? 'foo) => #t
- (symbol? (car '(a b))) => #t
- (symbol? "bar") => #f
- (symbol? 'nil) => #t
- (symbol? ')() => #f
- (symbol? #f) => #f

(symbol->string symbol) procedure

Returns the name of symbol as a string. It is an error to apply mutation procedures like string-set! to strings returned by this procedure.

- (symbol->string 'flying-fish) => "flying-fish"
- (symbol->string 'Martin) => "Martin"
- (symbol->string (string->symbol "Malvina")) => "Malvina"

(string->symbol string) procedure

Returns the symbol whose name is string. This procedure can create symbols with names containing special characters that would require escaping when written.

- (string->symbol "mISSISSIppl") => #f
- (eq? 'bitBlt (string->symbol "bitBlt")) => #t
- (eq? 'JollyWog (symbol->string 'JollyWog))) => #t
- (string=? "K. Harper, M.D.") => #t
- (string=? (string->symbol "K. Harper, M.D.")) => #t

6.3.4. Characters

Characters are objects that represent printed characters such as letters and digits. All Scheme implementations must support at least the ASCII character repertoire: that is, Unicode characters U+0000 through U+007F. Implementations may support any other Unicode characters they see fit, and may also support non-Unicode characters as well. Except as otherwise specified, the result of applying any of the following procedures to a non-Unicode character is implementation-dependent. Characters are written using the notation #\(character\) or #\x{hex scalar value}. For example:

- #\a ; lower case letter
- #\A ; upper case letter
- #\( ; left parenthesis
- #\ ; the space character
- #\space ; the preferred way to write a space
- #\tab ; the tab character
- #\return ; the return character, U+000D
- #\null ; the null character, U+0000
- #\alarm ; U+0007
- #\backspace ; U+0008
- #\escape ; U+001B
- #\delete ; U+007F
- #\x03BB ; \lambda (if supported)

Case is significant in #\(character\), and in #\x{hex scalar value}. If (character) in #\(character\) is alphabetic, then the character following (character) must be a delimiter character such as a space or parenthesis. This rule resolves the ambiguous case where, for example, the sequence of characters "#\space" could be taken to be either a representation of the space character or a representation of the character "#\s" followed by a representation of the symbol "pace."

Characters written in the #\ notation are self-evaluating. That is, they do not have to be quoted in programs.

Some of the procedures that operate on characters ignore the difference between upper case and lower case. The procedures that ignore case have "-ci" (for "case insensitive") embedded in their names.

(char? obj) procedure

Returns #t if obj is a character, otherwise returns #f.

- (char? 'char1 char2) procedure
- (char<? char1 char2) procedure
- (char>? char1 char2) procedure
- (char<=? char1 char2) procedure
- (char>=? char1 char2) procedure

These procedures impose a total ordering on the set of characters which is the same as the Unicode code point ordering. This is true independent of whether the implementation uses the Unicode representation internally.

Some implementations may generalize these procedures to take more than two arguments, as with the corresponding numerical predicates.
6. Standard procedures

(char-ci<=? char₁ char₂)  unicode module procedure
(char-ci=>? char₁ char₂)  unicode module procedure

These procedures are similar to char= et cetera, but they treat upper case and lower case letters as the same. For example, (char-ci=? #\A #\a) returns #t.

Specifically, these procedures behave as if char-foldcase were applied to their arguments before comparing them.

Some implementations may generalize these procedures to take more than two arguments, as with the corresponding numerical predicates.

(char-alphabetic? char)  procedure
(char-numeric? char)  procedure
(char-whitespace? char)  procedure
(char-upper-case? letter)  procedure
(char-lower-case? letter)  procedure

These procedures return #t if their arguments are alphabetic, numeric, whitespace, upper case, or lower case characters, respectively, otherwise they return #f.

Specifically, they must return #t when applied to characters with the Unicode properties Alphabetic, Numeric, White_Space, Uppercase, and Lowercase respectively, and #f when applied to any other Unicode characters. Note that many Unicode characters are alphabetic but neither upper nor lower case.

(char->integer char)  procedure
(integer->char n)  procedure

Given a Unicode character, char->integer returns an exact integer between 0 and #xD7FF or between #xE000 and #x10FFFF which is equal to the Unicode code point of that character. Given a non-Unicode character, it returns an exact integer greater than #x10FFFF. This is true independent of whether the implementation uses the Unicode representation internally.

Given an exact integer that is the image of a character under char->integer, integer->char returns that character.

(char-upcase char)  unicode module procedure
(char-downcase char)  unicode module procedure
(char-foldcase char)  unicode module procedure

The char-upcase procedure, given an argument that forms the lowercase part of a Unicode casing pair, returns the uppercase member of the pair, provided that both characters are supported by the Scheme implementation. Note that Turkic casing pairs are not used. If the argument is not the uppercase part of such a pair, it is returned.

The char-foldcase procedure applies the Unicode simple case-folding algorithm to its argument and returns the result. Note that Turkic-specific folding is not used. If the argument is an uppercase letter, the result will be a lowercase letter.

Note that many Unicode lowercase characters don’t have uppercase equivalents.

6.3.5. Strings

Strings are sequences of characters. Implementations may support characters that they do not allow to appear in strings. Strings are written as sequences of characters enclosed within doublequotes ("). Within a string literal, various escape sequences represent characters other than themselves. Escape sequences always start with a backslash (\):

- \a: alarm, U+0007
- \b: backspace, U+0008
- \t: character tabulation, U+0009
- \n: linefeed, U+000A
- \r: return, U+000D
- \": doublequote, U+0022
- \\: backslash, U+005C
- \x⟨hex scalar value⟩: specified character (note the terminating semi-colon).

The result is unspecified if any other character in a string occurs after a backslash.

A string constant may continue from one line to the next, which has the same effect as inserting a \n character into the string.

Example:

"The word "recursion" has many meanings."

The length of a string is the number of characters that it contains. This number is an exact, non-negative integer that is fixed when the string is created. The valid indexes of a string are the exact non-negative integers less than the length of the string. The first character of a string has index 0, the second has index 1, and so on.

In phrases such as “the characters of string beginning with index start and ending with index end,” it is understood
that the index start is inclusive and the index end is exclusive. Thus if start and end are the same index, a null substring is referred to, and if start is zero and end is the length of string, then the entire string is referred to.

Some of the procedures that operate on strings ignore the difference between upper and lower case. The versions that ignore case have “-ci” (for “case insensitive”) embedded in their names.

```
(string? obj) procedure
Returns #t if obj is a string, otherwise returns #f.

(make-string k) procedure
(make-string k char) procedure
Make-string returns a newly allocated string of length k. If char is given, then all elements of the string are initialized to char, otherwise the contents of the string are unspecified.

(string char ...) procedure
Returns a newly allocated string composed of the arguments.

(string-length string) procedure
Returns the number of characters in the given string.

(string-ref string k) procedure
k must be a valid index of string. String-ref returns character k of string using zero-origin indexing.

(string-set! string k char) procedure
k must be a valid index of string. String-set! stores char in element k of string and returns an unspecified value.

(define (f) (make-string 3 '#*'))
(define (g) '***')
(string-set! (f) 0 '#?) ==> unspecified
(string-set! (g) 0 '#?) ==> error
(string-set! (symbol->string 'immutable) 0 '#?) ==> error

(string=? string1 string2) procedure
Returns #t if the two strings are the same length and contain exactly the same characters in the same positions, otherwise returns #f. Specifically, these procedures behave as if string-foldcase were applied to their arguments before comparing them.

(string-ni=? string1 string2) Unicode module procedure
Returns #t if, after an implementation-defined normalization, the two strings are the same length and contain the same characters in the same positions, otherwise returns #f. The intent is to provide a means of comparing strings that should be considered equivalent in some situations but may be represented by a different sequence of characters. Specifically, an implementation which supports Unicode should consider using Unicode normalization NFC or NFD as specified by Unicode TR#15. Implementations which only support ASCII or some other character set which provides no ambiguous representations of character sequences may define the normalization to be the identity operation, in which case string-ni=? is equivalent to string=?.

(string-ci=? string1 string2) Unicode module procedure
(string-ci<? string1 string2) Unicode module procedure
(string-ci>=? string1 string2) Unicode module procedure
(string-ci<=? string1 string2) Unicode module procedure
(string-ci>? string1 string2) Unicode module procedure
(string-ci<? string1 string2) Unicode module procedure

These procedures compare strings in an implementation-defined way. One approach is to make them the lexicographic extensions to strings of the corresponding orderings on characters. In that case, string-ci<? would be the lexicographic ordering on strings induced by the ordering char-ci< on characters, and if the two strings differ in length but are the same up to the length of the shorter string, the shorter string would be considered to be lexicographically less than the longer string. However, it is also permitted to use the natural ordering imposed by the internal representation of strings, or a more complex locale-specific ordering.

In all cases, a pair of strings must satisfy exactly one of string<?, string=?, and string>?,
The “-ci” procedures behave as if they applied string-foldcase to their arguments before invoking the corresponding procedures without “-ci”.

The “-ni” procedures behave as if they applied the implementation-defined normalization used by string-ni=? to their arguments before invoking the corresponding procedures without “-ni”.

Implementations may generalize these and the string=?, string-ci=?, and string-ni=? procedures to take more than two arguments, as with the corresponding numerical predicates.

(string-upcase string) unicode module procedure
(string-downcase string) unicode module procedure
(string-foldcase string) unicode module procedure

These procedures apply the Unicode full string uppercasing, lowercasing, and case-folding algorithms to their arguments and return the result. Note that Turkic-specific mappings and foldings are not used. The result may differ in length from the argument. What is more, a few characters have case-mappings that depend on the surrounding context. For example, Greek capital sigma normally lowercases to Greek small sigma, but at the end of a word it downcases to Greek small final sigma instead.

(substring string start end) procedure

String must be a string, and start and end must be exact integers satisfying

0 ≤ start ≤ end ≤ (string-length string).

Substring returns a newly allocated string formed from the characters of string beginning with index start (inclusive) and ending with index end (exclusive).

(string-append string ...) procedure

Returns a newly allocated string whose characters form the concatenation of the given strings.

(string->list string) procedure
(list->string list) procedure

String->list returns a newly allocated list of the characters that make up the given string. List->string returns a newly allocated string formed from the characters in the list list, which must be a list of characters. String->list and list->string are inverses so far as equal? is concerned.

(string-copy string) procedure

Returns a newly allocated copy of the given string.

(string-fill! string char) procedure

Stores char in every element of the given string and returns an unspecified value.

6.3.6. Vectors

Vectors are heterogeneous structures whose elements are indexed by integers. A vector typically occupies less space than a list of the same length, and the average time required to access a randomly chosen element is typically less for the vector than for the list.

The length of a vector is the number of elements that it contains. This number is a non-negative integer that is fixed when the vector is created. The valid indexes of a vector are the exact non-negative integers less than the length of the vector. The first element in a vector is indexed by zero, and the last element is indexed by one less than the length of the vector.

Vectors are written using the notation #(obj ...). For example, a vector of length 3 containing the number zero in element 0, the list (2 2 2 2) in element 1, and the string "Anna" in element 2 can be written as following:

#(0 (2 2 2 2) "Anna")

Note that this is the external representation of a vector, not an expression evaluating to a vector. Like list constants, vector constants must be quoted:

' #(0 (2 2 2 2) "Anna") ⇒ #(0 (2 2 2 2) "Anna")

(vector? obj) procedure

Returns #t if obj is a vector, otherwise returns #f.

(make-vector k) procedure
(make-vector k fill) procedure

Returns a newly allocated vector of k elements. If a second argument is given, then each element is initialized to fill. Otherwise the initial contents of each element is unspecified.

(vector obj ...) procedure

Returns a newly allocated vector whose elements contain the given arguments. Analogous to list.

(vector 'a 'b 'c) ⇒ #(a b c)
6.3.7. Blobs

Blobs are a disjoint type for representing blocks of binary data. Conceptually, blobs can be thought of as homogeneous vectors of 8-bit bytes, but they typically occupy less space than a vector.

The length of a blob is the number of elements that it contains. This number is a non-negative integer that is fixed when the blob is created. The valid indexes of a blob are the exact non-negative integers less than the length of the blob, starting at index zero as with vectors.

(blob? obj)                      procedure
Returns #t if obj is a blob.

(make-blob k)                    procedure
Returns a newly allocated blob of k bytes. The initial contents of each element is unspecified.

(blob-length blob)               procedure
Returns the length of blob in bytes as an exact integer.

(blob-u8-ref blob k)             procedure
Returns the kth byte of blob as an exact integer in the range [0..255].

(blob-u8-set! blob k u8)         procedure
Stores u8 as the kth byte of blob. u8 must be an exact integer in the range [0..255]. The value returned by blob-u8-set! is unspecified.

(blob-copy blob)                 procedure
Returns a newly allocated blob containing the same bytes as blob.

(blob-copy! from to)             procedure
Copy the bytes of blob from to blob to, which must not be shorter. The value returned by copy-blob! is unspecified.

(partial-blob blob start end)    procedure
Returns a newly allocated blob containing the bytes in blob between start (inclusive) and end (exclusive).

(partial-blob-copy! from start end to at) procedure
Copy the bytes of blob from between start and end to blob to, starting at at. The order in which bytes are copied...
is unspecified, except that if the source and destination overlap, copying takes place as if the source is first copied into a temporary blob and then into the destination. This can be achieved without allocating storage by making sure to copy in the correct direction in such circumstances.

The inequality \( \geq (- (\text{blob-length} \text{to}) \text{at}) (- \text{end} \text{start}) \) must be true. The value returned by \text{copy-blob!} is unspecified.

### 6.4. Control features

This chapter describes various primitive procedures which control the flow of program execution in special ways. The \text{procedure?} predicate is also described here.

```
(procedure? obj) \text{procedure}
```

Returns \#t if \text{obj} is a procedure, otherwise returns \#f.

```
(procedure? car) \Rightarrow \#t
(procedure? 'car) \Rightarrow \#f
(procedure? (lambda (x) (* x x))) \Rightarrow \#t
(procedure? '(lambda (x) (* x x))) \Rightarrow \#f
(call-with-current-continuation procedure?) \Rightarrow \#t
```

```
(apply proc arg_1 ... args) \text{procedure}
```

\text{Proc} must be a procedure and \text{args} must be a list. Calls \text{proc} with the elements of the list \((\text{append} (\text{list} \text{arg_1} ... \text{args}))\) as the actual arguments.

```
(apply + (list 3 4)) \Rightarrow 7

(define compose
  (lambda (f g)
    (lambda args
      (f (apply g args)))))

((compose sqrt *) 12 75) \Rightarrow 30
```

```
(map proc list_1 list_2 ...) \text{procedure}
```

The \text{lists} must be lists, and \text{proc} must be a procedure taking as many arguments as there are \text{lists} and returning a single value. If more than one \text{list} is given and not all lists have the same length, \text{map} terminates when the shortest list runs out. \text{Map} applies \text{proc} element-wise to the elements of the \text{lists} and returns a list of the results, in order. The dynamic order in which \text{proc} is applied to the elements of the \text{lists} is unspecified.

```
(map cadr '((a b) (d e) (g h))) \Rightarrow (b e h)
(map (lambda (n) (expt n n)) '(1 2 3 4 5)) \Rightarrow (1 4 27 256 3125)
(map + '(1 2 3) '(4 5 6)) \Rightarrow (5 7 9)
(let ((count 0))
  (map (lambda (ignored)
         (set! count (+ count 1))
         count)
       '(a b))) \Rightarrow (1 2 or 2 1)
```

```
(string-map proc string_1 string_2 ...) \text{procedure}
```

The \text{strings} must be strings, and \text{proc} must be a procedure taking as many arguments as there are \text{strings} and returning a single value. If more than one \text{string} is given and not all strings have the same length, \text{string-map} terminates when the shortest list runs out. \text{String-map} applies \text{proc} element-wise to the elements of the \text{strings} and returns a string of the results, in order. The dynamic order in which \text{proc} is applied to the elements of the \text{strings} is unspecified.

```
(string-map char-foldcase "AbdEgH") \Rightarrow "abdegh"
(string-map
  (lambda (c)
    (integer->char (+ 1 (char->integer c))))
  "HAL") \Rightarrow "IBM"
(string-map
  (lambda (c k)
    (if (eqv? k #\u)
     (char-upcase c)
     (char-downcase c)))
  "studlycaps"
  "ululululul") \Rightarrow "StUDLyCaPs"
```

```
(vector-map proc vector_1 vector_2 ...) \text{procedure}
```

The \text{vectors} must be vectors, and \text{proc} must be a procedure taking as many arguments as there are \text{vectors} and returning a single value. If more than one \text{vector} is given and not all vectors have the same length, \text{vector-map} terminates when the shortest list runs out. \text{Vector-map} applies \text{proc} element-wise to the elements of the \text{vectors} and returns a vector of the results, in order. The dynamic order in which \text{proc} is applied to the elements of the \text{vectors} is unspecified.

```
(vector-map cadr '#((a b) (d e) (g h))) \Rightarrow #((a b) (d e) (g h))
```

```
(map cadr '(a b) (d e) (g h)) \Rightarrow (b e h)
```
(vector-map (lambda (n) (expt n n))
  '#(1 2 3 4 5))
⇒ #(1 4 27 256 3125)

(vector-map + '#(1 2 3) '#(4 5 6))
⇒ #(5 7 9)

(let ((count 0))
  (vector-map (lambda (ignored)
               (set! count (+ count 1))
               count)
  '#(a b)))
⇒ #(1 2) or #(2 1)

(for-each proc list1 list2 ...) procedure

The arguments to for-each are like the arguments to map, but for-each calls proc for its side effects rather than for its values. Unlike map, for-each is guaranteed to call proc on the elements of the lists in order from the first element(s) to the last, and the value returned by for-each is unspecified. If more than one list is given and not all lists have the same length, for-each terminates when the shortest list runs out.

(string-for-each proc string1 string2 ...) procedure

The arguments to string-for-each are like the arguments to string-map, but string-for-each calls proc for its side effects rather than for its values. Unlike string-map, string-for-each is guaranteed to call proc on the elements of the lists in order from the first element(s) to the last, and the value returned by string-for-each is unspecified. If more than one string is given and not all strings have the same length, string-for-each terminates when the shortest string runs out.

(vector-for-each proc vector1 vector2 ...) procedure

The arguments to vector-for-each are like the arguments to vector-map, but vector-for-each calls proc for its side effects rather than for its values. Unlike vector-map, vector-for-each is guaranteed to call proc on the elements of the vectors in order from the first element(s) to the last, and the value returned by vector-for-each is unspecified. If more than one vector is given and not all vectors have the same length, vector-for-each terminates when the shortest vector runs out.

(force promise) lazy module procedure

Forces the value of promise (see delay, section 4.2.5). If no value has been computed for the promise, then a value is computed and returned. The value of the promise is cached (or “memoized”) so that if it is forced a second time, the previously computed value is returned.

(define a-stream
  (letrec ((next
              (lambda (n)
                (cons n (delay (next (+ n 1)))))))
    (next 0)))

(define head car)
(define tail
  (lambda (stream) (force (cdr stream))))

(head (tail (tail a-stream)))
⇒ 2

Force and delay are mainly intended for programs written in functional style. The following examples should not be considered to illustrate good programming style, but they illustrate the property that only one value is computed for a promise, no matter how many times it is forced.

(define count 0)
(define p
  (delay (begin (set! count (+ count 1))
               (if (> count x)
                   count
                   (force p)))))

(define x 5)
(p 5) ⇒ a promise
(force p) ⇒ 6
(p 5) ⇒ a promise, still
(force p) ⇒ 6

Here is a possible implementation of delay and force. Promises are implemented here as procedures of no arguments, and force simply calls its argument:

(define force
  (lambda (object)
    (object)))
We define the expression

\( \text{delay } (\langle \text{expression} \rangle) \)

to have the same meaning as the procedure call

\( \text{make-promise } (\lambda () (\langle \text{expression} \rangle)) \)

as follows

\[
(\text{define-syntax delay}
\quad (\text{syntax-rules ()}
\quad ((\text{delay expression})
\quad (\text{make-promise } (\lambda () \text{expression}))))),
\]

where \text{make-promise} is defined as follows:

\[
(\text{define make-promise}
\quad (\lambda (proc)
\quad (\begin{align*}
\text{let } ((\text{result-ready?} \ #f) & \quad \text{(result } #f)) \\
\text{(lambda } () & \quad (\begin{align*}
\text{(if result-ready?} & \quad \text{result} \\
\text{(let } ((x \ (proc))) & \quad (\begin{align*}
\text{(if result-ready?} & \quad \text{result} \\
\text{(begin } & \quad (\begin{align*}
\text{(set! result-ready? } & \#t) \\
\text{(set! result } x) \\
\text{result})\\
\end{align*})\\
\text{result))))))))
\end{align*})
\end{align*})
\end{align*})
\)
\]

Rationale: A promise may refer to its own value, as in the last example above. Forcing such a promise may cause the promise to be forced a second time before the value of the first force has been computed. This complicates the definition of make-promise.

Various extensions to this semantics of \text{delay} and \text{force} are supported in some implementations:

- Calling \text{force} on an object that is not a promise may simply return the object.

- It may be the case that there is no means by which a promise can be operationally distinguished from its forced value. That is, expressions like the following may evaluate to either \#t or to \#f, depending on the implementation:

\[
(\text{eqv? } (\text{delay } 1) 1) \quad \Rightarrow \text{unspecified}
(\text{pair? } (\text{delay } (\text{cons } 1 2))) \quad \Rightarrow \text{unspecified}
\]

- Some implementations may implement “implicit forcing,” where the value of a promise is forced by primitive procedures like \text{cdr} and +:

\[
(\text{+ } (\text{delay } (* \ 3 \ 7)) \ 13) \quad \Rightarrow \ 34
\]

\( (\text{call-with-current-continuation } \text{proc}) \quad \text{procedure}
\)
\( (\text{call/cc } \text{proc}) \quad \text{procedure}
\)

\text{Proc} must be a procedure of one argument. The procedure \text{call-with-current-continuation} (or its equivalent abbreviation \text{call/cc}) packages up the current continuation (see the rationale below) as an “escape procedure” and passes it as an argument to \text{proc}. The escape procedure is a Scheme procedure that, if it is later called, will abandon whatever continuation is in effect at that later time and will instead use the continuation that was in effect when the escape procedure was created. Calling the escape procedure may cause the invocation of \text{before} and \text{after} thunks installed using \text{dynamic-wind}.

The escape procedure accepts the same number of arguments as the continuation to the original call to \text{call-with-current-continuation}. Except for continuations created by the \text{call-with-values} procedure, all continuations take exactly one value. The effect of passing no value or more than one value to continuations that were not created by \text{call-with-values} is unspecified.

The escape procedure that is passed to \text{proc} has unlimited extent just like any other procedure in Scheme. It may be stored in variables or data structures and may be called as many times as desired.

The following examples show only the most common ways in which \text{call-with-current-continuation} is used. If all real uses were as simple as these examples, there would be no need for a procedure with the power of \text{call-with-current-continuation}.

\[
(\text{call-with-current-continuation}
\quad (\lambda (\text{exit})
\quad (\text{for-each } (\lambda (x)
\quad (\text{if } (\text{negative? } x)
\quad (\text{exit } x))
\quad \'(54 \ 0 \ 37 \ -3 \ 245 \ 19))
\quad \#t))
\quad \Rightarrow \ -3
\)

\( (\text{define list-length}
\quad (\lambda (\text{obj})
\quad (\text{call-with-current-continuation}
\quad (\lambda (\text{return})
\quad (\begin{align*}
\text{letrec } ((r \ (\lambda (\text{obj})
\quad (\begin{align*}
\text{(cond } ((\text{null? } \text{obj}) 0)
\quad ((\text{pair? } \text{obj})
\quad (+ \ (r \ (\text{cdr obj})) 1))
\quad (\text{else } (\text{return } \#f))))))
\quad \text{(r } \text{obj})))))
\quad (\text{list-length } \'(1 \ 2 \ 3 \ 4)) \quad \Rightarrow \ 4
\quad (\text{list-length } \'(a \ b \ c)) \quad \Rightarrow \ \#f
\)

Rationale:

A common use of \text{call-with-current-continuation} is for structured, non-local exits from loops or procedure bodies, but
in fact \texttt{call-with-current-continuation} is extremely useful for implementing a wide variety of advanced control structures.

Whenever a Scheme expression is evaluated there is a continuation wanting the result of the computation. The continuation represents an entire (default) future for the computation. If the expression is evaluated at top level, for example, then the continuation might take the result, print it on the screen, prompt for the next input, evaluate it, and so on forever. Most of the time the continuation includes actions specified by user code, as in a continuation that will take the result, multiply it by the value stored in a local variable, add seven, and give the answer to the top level continuation to be printed. Normally these ubiquitous continuations are hidden behind the scenes and programmers do not think much about them. On rare occasions, however, a programmer may need to deal with continuations explicitly. \texttt{Call-with-current-continuation} allows Scheme programmers to do that by creating a procedure that acts just like the current continuation.

Most programming languages incorporate one or more special-purpose escape constructs with names like \texttt{exit}, \texttt{return}, or even \texttt{goto}. In 1965, however, Peter Landin [18] invented a general purpose escape operator called the J-operator. John Reynolds [26] described a simpler but equally powerful construct in 1972. The \texttt{catch} special form described by Sussman and Steele in the 1975 report on Scheme is exactly the same as Reynolds’s construct, though its name came from a less general construct in MacLisp. Several Scheme implementors noticed that the full power of the \texttt{catch} construct could be provided by a procedure instead of by a special syntactic construct, and the name \texttt{call-with-current-continuation} was coined in 1982. This name is descriptive, but opinions differ on the merits of such a long name, and some people use the name \texttt{call/cc} instead.

\begin{verbatim}
(values obj ...) multiple-values module procedure

Delivers all of its arguments to its continuation. Except for continuations created by the \texttt{call-with-values} procedure, all continuations take exactly one value. \texttt{Values} might be defined as follows:

\begin{verbatim}
(define (values . things)
  (call-with-current-continuation
   (lambda (cont) (apply cont things))))
\end{verbatim}

\begin{verbatim}
(call-with-values producer consumer) multiple-values module procedure

Calls its \texttt{producer} argument with no values and a continuation that, when passed some values, calls the \texttt{consumer} procedure with those values as arguments. The continuation for the call to \texttt{consumer} is the continuation of the call to \texttt{call-with-values}.

\begin{verbatim}
(call-with-values (lambda () (values 4 5))
  (lambda (a b) b))
\end{verbatim}
\end{verbatim}

\begin{verbatim}
(call-with-values + -) \Rightarrow -1
\end{verbatim}

\begin{verbatim}
(dynamic-wind before thunk after) procedure

Calls \texttt{thunk} without arguments, returning the result(s) of this call. \texttt{Before} and \texttt{after} are called, also without arguments, as required by the following rules (note that in the absence of calls to continuations captured using \texttt{call-with-current-continuation} the three arguments are called once each, in order). \texttt{Before} is called whenever execution enters the dynamic extent of the call to \texttt{thunk} and \texttt{after} is called whenever it exits that dynamic extent. The dynamic extent of a procedure call is the period between when the call is initiated and when it returns. In Scheme, because of \texttt{call-with-current-continuation}, the dynamic extent of a call may not be a single, connected time period. It is defined as follows:

\begin{itemize}
  \item The dynamic extent is entered when execution of the body of the called procedure begins.
  \item The dynamic extent is also entered when execution is not within the dynamic extent and a continuation is invoked that was captured (using \texttt{call-with-current-continuation}) during the dynamic extent.
  \item It is exited when the called procedure returns.
  \item It is also exited when execution is within the dynamic extent and a continuation is invoked that was captured while not within the dynamic extent.
\end{itemize}

If a second call to \texttt{dynamic-wind} occurs within the dynamic extent of the call to \texttt{thunk} and then a continuation is invoked in such a way that the \texttt{afters} from these two invocations of \texttt{dynamic-wind} are both to be called, then the \texttt{after} associated with the second (inner) call to \texttt{dynamic-wind} is called first.

If a second call to \texttt{dynamic-wind} occurs within the dynamic extent of the call to \texttt{thunk} and then a continuation is invoked in such a way that the \texttt{befores} from these two invocations of \texttt{dynamic-wind} are both to be called, then the \texttt{before} associated with the first (outer) call to \texttt{dynamic-wind} is called first.

If invoking a continuation requires calling the \texttt{before} from one call to \texttt{dynamic-wind} and the \texttt{after} from another, then the \texttt{after} is called first.

The effect of using a captured continuation to enter or exit the dynamic extent of a call to \texttt{before} or \texttt{after} is undefined.

\begin{verbatim}
(let ((path '()))
  (c #f))
\end{verbatim}
\end{verbatim}

\begin{verbatim}
(let ((add (lambda (s)
\end{verbatim}

(set! path (cons s path))
(dynamic-wind
 (lambda () (add 'connect))
 (lambda ()
   (add (call-with-current-continuation
         (lambda (c0)
           (set! c c0)
           'talk1))))
 (lambda () (add 'disconnect)))
 (if (< (length path) 4)
   (c 'talk2)
   (reverse path)))
⇒ (connect talk1 disconnect
c      connect talk2 disconnect)

(make-parameter init)  procedure
(make-parameter init converter)  procedure

Returns a new parameter object which is associated with
the value returned by the call (converter init). If the
conversion procedure converter is not specified the identity
function is used instead.

A parameter object is a procedure which accepts zero ar-
erguments and returns its associated value. The associated
value may be changed with parameterize.

Here is a possible implementation of make-parameter and
parameterize suitable for an implementation with no
threads. Parameter objects are implemented here as pro-
cedures, using two arbitrary unique objects <param-set!>
and <param-convert>:

(define (make-parameter init . o)
 (let* ((converter (if (pair? o)
                          (car o)
                          (lambda (x) x)))
        (value (converter init)))
        (lambda args
        (if (pair? args)
            (cond
              ((eq? (car args) <param-set!>)
               (set! value (cadr args)))
              ((eq? (car args) <param-convert>)
               converter)
            (else
             (error "bad parameter syntax")))))

Parameterize then uses dynamic-wind to dynamically re-
binding the associated value:

(define-syntax parameterize
 (syntax-rules ()
   ((parameterize (“step”)
     (param value p old new) ...)
    (let ((params (cons (param old) params)))
     (let ((old (p)) ...
           (new ((p <param-convert>) value)) ...
           (param value p new new) ...
           (new (params value) ...)))))
   (dynamic-wind
    (lambda () (p <param-set!> new) ...)
    (lambda (). body)
    (lambda () (p <param-set!> old) ...)))))

Parameter objects can be used to specify configurable set-
tings for a computation without the need to explicitly pass
the value to every procedure in the call chain.

(define radix
 (make-parameter
  10
  (lambda (x)
    (if (and (integer? x) (<= 2 x 16))
      x
      (error "invalid radix")))))

(define (f n) (number->string n (radix)))
(f 12)  ⇒ "12"
(parameterize ((radix 16))
  (f 12))  ⇒ "C"
  (f 12)  ⇒ "12"
  (radix 16)  ⇒ unspecified
  (parameterize ((radix 0))
    (f 12))  ⇒ error

6.5. Exceptions

This section describes Scheme's exception-handling and
exception-raising constructs.

Exception handlers are one-argument procedures that de-
termine the action the program takes when an exceptional
situation is signalled. The system implicitly maintains a
current exception handler.

The program raises an exception by invoking the current
exception handler, passing it an object encapsulating in-
formation about the exception. Any procedure accepting
one argument may serve as an exception handler and any
object may be used to represent an exception.

(with-exception-handler handler thunk) procedure
Handler must be a procedure and should accept one ar-
gument. Thunk must be a procedure that accepts zero
arguments. The with-exception-handler procedure re-
turns the results of invoking thunk. Handler is installed as
the current exception handler for the dynamic extent (as
determined by dynamic-wind) of the invocation of thunk.

(raise obj) procedure
Raises a exception by invoking the current exception han-
dler on obj. The handler is called with a continuation
whose dynamic extent is that of the call to raise, except
that the current exception handler is the one that was in
place when the handler being called was installed. If the
handler returns, an exception is raised in the same dynamic
extent as the handler.

(raise-continuable obj) procedure
Raises an exception by invoking the current exception han-
dler on obj. The handler is called with a continuation
that is equivalent to the continuation of the call to raise-
continuable, with these two exceptions: (1) the current
exception handler is the one that was in place when the
handler being called was installed, and (2) if the han-
dler being called returns, then it will again become the
current exception handler. If the handler returns, the val-
ues it returns become the values returned by the call to
raise-continuable.

(error message obj ...) procedure
Message should be a string. A convenience procedure to
raise an exception. Equivalent to calling raise on an
implementation-defined object which encapsulates the in-
formation provided by message and any objs.

(with-exception-handler
 (lambda (con)
   (cond
     ((string? con)
      (display con))
   (else
    (display "a warning has been issued")))
  42)
(lambda ()
  (+ (raise-continuable "should be a number")
     23)))
prints: should be a number
⇒ 65

6.6. Eval

(eval expression environment-specifier) procedure
Evaluates expression in the specified environment and re-
turns its value. Expression must be a valid Scheme expres-
sion represented as data, and environment-specifier must
be a value returned by one of the three procedures de-
scribed below. Implementations may extend eval to al-
low non-expression programs (definitions) as the first ar-
gument and to allow other values as environments, with
the restriction that eval is not allowed to create new bind-
ings in the environments returned by null-environment
or scheme-report-environment.

(eval '(+ 7 3) (scheme-report-environment 5))
⇒ 21

(let ((f (eval '(lambda (f x) (f x x))
     (null-environment 5))))
  (f + 10))
⇒ 20

(scheme-report-environment version) procedure
(null-environment version) procedure
Version must be the exact integer 7, corresponding to this
revision of the Scheme report (the Revised7 Report on
Scheme). Scheme-report-environment returns a specifier
for an environment that is empty except for all bindings de-
filed in this report that are either required or both optional
and supported by the implementation. Null-environment
returns a specifier for an environment that is empty except
for the (syntactic) bindings for all syntactic keywords de-
defined in this report that are either required or both optional
and supported by the implementation.

Other values of version can be used to specify environments
matching past revisions of this report, but their support is
not required. An implementation must signal an error if
version is neither 7 nor another value supported by the
implementation.

The effect of assigning (through the use of eval) a vari-
able bound in a scheme-report-environment (for ex-
ample car) is unspecified. Thus the environments specified
by scheme-report-environment may be immutable.

(interaction-environment) repl module procedure
This procedure returns a specifier for the environment that
contains implementation-defined bindings, typically a su-
perset of those listed in the report. The intent is that this
procedure will return the environment in which the imple-
mentation would evaluate expressions dynamically typed
by the user.
6.7. Input and output

6.7.1. Ports

Ports represent input and output devices. To Scheme, an input port is a Scheme object that can deliver data upon command, while an output port is a Scheme object that can accept data. Different port types operate on different data. Scheme implementations are required to support character ports and binary ports, but may also provide other port types.

A character port supports reading or writing of character data, such as read-char and write-char below, as well as operations defined in terms of characters such as read and write.

A binary port supports reading or writing of binary data at the level of individual octets with read-u8 and write-u8, below. Every binary port is also automatically a character port, by treating the sequence of octets as an implementation-determined character set encoding. Conversely, not all character ports are binary ports - for example, the string ports discussed below.

Ports can be used to access objects called files on the host system in which the Scheme program is running. In the procedures below files are referenced with (file-spec)s, which can either be a string or a settings list, which is a list of alternating (keys) and (values) where every (key) is a symbol. Specifying a string is equivalent to the settings list (path string). The following keys are defined:

- **path** - A string naming the file. The interpretation of filenames is implementation-dependent. There is no default value, but implementations may accept other keys in lieu of this for opening file objects that don’t have string names.

- **buffer** - Specifies what kind of buffering is present. The value #f means no buffering is employed; the symbol binary means that there is a binary buffer but no character buffer; #t means there are both character and binary buffering. Other values may be specified by an implementation. Buffer sizes are implementation-dependent. The default value is implementation-dependent.

Implementations may support other keys, should warn if they detect keys they do not understand or implement, and may signal an error in such cases.

```
(call-with-input-file file-spec proc)  ; file module procedure
(call-with-output-file file-spec proc) ; file module procedure
```

Proc should be a procedure that accepts one argument. For call-with-input-file, the file named by file-spec should already exist; for call-with-output-file, the effect is unspecified if the file already exists. These procedures call proc with one argument: the port obtained by opening the named file for input or output. If the file cannot be opened, an error is signalled. If proc returns, then the port is closed automatically and the value(s) yielded by the proc is(are) returned. If proc does not return, then the port will not be closed automatically unless it is possible to prove that the port will never again be used for a read or write operation.

**Rationale:** Because Scheme’s escape procedures have unlimited extent, it is possible to escape from the current continuation but later to escape back in. If implementations were permitted to close the port on any escape from the current continuation, then it would be impossible to write portable code using both call-with-current-continuation and call-with-input-file or call-with-output-file.

```
(input-port? obj)  ; io module procedure
(output-port? obj) ; io module procedure
(port? obj)        ; io module procedure
```

Returns #t if obj is an input port, output port, or any kind of port, respectively, otherwise returns #f.

```
(character-port? obj)  ; io module procedure
(binary-port? obj)     ; io module procedure
```

Returns #t if obj is a character port or binary port, respectively.

```
(port-open? port)       ; io module procedure
```

Returns #t if port is still open and capable of performing input or output, and #f otherwise.

```
(current-input-port)    ; io module procedure
(current-output-port)    ; io module procedure
(current-error-port)     ; io module procedure
```

Returns the current default input port, output port, or error port (an output port), respectively. These are parameter objects, which can be overridden with parameterize (see section 6.4). The initial bindings for each of these are bound to system defined binary ports.

```
(with-input-from-file file-spec thunk) ; file module procedure
(with-output-to-file file-spec thunk)   ; file module procedure
```

Proc should be a procedure of no arguments. For with-input-from-file, the file named by file-spec should already exist; for with-output-to-file, the effect is unspecified if the file already exists. The file is opened for input or output, a binary input or output port
connected to it is made the default value returned by current-input-port or current-output-port (and is used by (read), (write obj), and so forth), and the thank is called with no arguments. When the thank returns, the port is closed and the previous default is restored. With-input-from-file and with-output-to-file return(s) the value(s) yielded by thank. If an escape procedure is used to escape from the continuation of these procedures, their behavior is implementation dependent.

(open-input-file file-spec) file module procedure
Takes a file-spec for an existing file and returns a binary input port capable of delivering data from the file. If the file cannot be opened, an error is signalled.

(open-output-file file-spec) file module procedure
Takes a file-spec naming an output file to be created and returns a binary output port capable of writing characters to a new file by that name. If the file cannot be opened, an error is signalled. If a file with the given name already exists, the effect is unspecified.

(close-input-port port) io module procedure
(close-output-port port) io module procedure
Closes the file associated with port, rendering the port incapable of delivering or accepting data. These routines have no effect if the file has already been closed. The value returned is unspecified.

(open-input-string string) io module procedure
Takes a string and returns a character input port that delivers characters from the string.

(open-output-string) io module procedure
Returns a character output port that will accumulate characters for retrieval by get-output-string.

(get-output-string port) io module procedure
Given an output port created by open-output-string, returns a string consisting of the characters that have been output to the port so far.

6.7.2. Input

(read) read module procedure
(read port) read module procedure
Read converts external representations of Scheme objects into the objects themselves. That is, it is a parser for the nonterminal ⟨datum⟩ (see sections 7.1.2 and 6.3.2). Read returns the next object parsable from the given character input port, updating port to point to the first character past the end of the external representation of the object.

If an end of file is encountered in the input before any characters are found that can begin an object, then an end of file object is returned. The port remains open, and further attempts to read will also return an end of file object. If an end of file is encountered after the beginning of an object's external representation, but the external representation is incomplete and therefore not parsable, an error is signalled.

The port argument may be omitted, in which case it defaults to the value returned by current-input-port. It is an error to read from a closed port.

(read-char) io module procedure
(read-char port) io module procedure
Returns the next character available from the character input port, updating the port to point to the following character. If no more characters are available, an end of file object is returned. Port may be omitted, in which case it defaults to the value returned by current-input-port.

(peek-char) io module procedure
(peek-char port) io module procedure
Returns the next character available from the character input port, without updating the port to point to the following character. If no more characters are available, an end of file object is returned. Port may be omitted, in which case it defaults to the value returned by current-input-port.

Note: The value returned by a call to peek-char is the same as the value that would have been returned by a call to read-char with the same port. The only difference is that the very next call to read-char or peek-char on that port will return the value returned by the preceding call to peek-char. In particular, a call to peek-char on an interactive port will hang waiting for input whenever a call to read-char would have hung.

(eof-object? obj) io module procedure
Returns #t if obj is an end of file object, otherwise returns #f. The precise set of end of file objects will vary among implementations, but in any case no end of file object will ever be an object that can be read in using read.

(char-ready?) io module procedure
(char-ready? port) io module procedure
Returns #t if a character is ready on the character input port and returns #f otherwise. If char-ready returns #t then the next read-char operation on the given port is guaranteed not to hang. If the port is at end of
file then char-ready? returns #t. Port may be omitted, in which case it defaults to the value returned by current-input-port.

Rationale: Char-ready? exists to make it possible for a program to accept characters from interactive ports without getting stuck waiting for input. Any input editors associated with such ports must ensure that characters whose existence has been asserted by char-ready? cannot be rubbed out. If char-ready? were to return #f at end of file, a port at end of file would be indistinguishable from an interactive port that has no ready characters.

(read-u8)  io module procedure
(read-u8 port)  io module procedure

Returns the next octet available from the binary input port, updating the port to point to the following octet. The value is an exact integer in the range [0..255]. If no more octets are available, an end of file object is returned. Port may be omitted, in which case it defaults to the value returned by current-input-port.

(peek-u8)  io module procedure
(peek-u8 port)  io module procedure

Returns the next octet available from the binary input port, without updating the port to point to the following character. If no more octets are available, an end of file object is returned. Port may be omitted, in which case it defaults to the value returned by current-input-port.

(u8-ready?)  io module procedure
(u8-ready? port)  io module procedure

Returns #t if an octet is ready on the binary input port and returns #f otherwise. If u8-ready? returns #t then the next read-u8 operation on the given port is guaranteed not to hang. If the port is at end of file then u8-ready? returns #t. Port may be omitted, in which case it defaults to the value returned by current-input-port.

Note: If u8-ready? returns #t, a subsequent read-char operation may still hang.

6.7.3. Output

(write obj)  write module procedure
(write obj port)  write module procedure

Writes a written representation of obj to the given character output port. Strings that appear in the written representation are enclosed in doublequotes, and within those strings backslash and doublequote characters are escaped by backslashes. Symbols that contain non-ASCII characters are escaped either with inline hex escapes or with vertical bars. Character objects are written using the #\ notation. Write returns an unspecified value. The port argument may be omitted, in which case it defaults to the value returned by current-output-port.

(display obj)  write module procedure
(display obj port)  write module procedure

Writes a representation of obj to the given character output port. Strings that appear in the written representation are not enclosed in doublequotes, and no characters are escaped within those strings. Symbols are not escaped. Character objects appear in the representation as if written by write-char instead of by write. Display returns an unspecified value. The port argument may be omitted, in which case it defaults to the value returned by current-output-port.

Rationale: Write is intended for producing machine-readable output and display is for producing human-readable output.

(newline)  io module procedure
(newline port)  io module procedure

Writes an end of line to character output port. Exactly how this is done differs from one operating system to another. Returns an unspecified value. The port argument may be omitted, in which case it defaults to the value returned by current-output-port.

(write-char char)  io module procedure
(write-char char port)  io module procedure

Writes the character char (not an external representation of the character) to the given character output port and returns an unspecified value. The port argument may be omitted, in which case it defaults to the value returned by current-output-port.

(write-u8 octet)  io module procedure
(write-u8 octet port)  io module procedure

 Writes the octet, an exact integer in the range [0..255], to the given binary output port and returns an unspecified value. The port argument may be omitted, in which case it defaults to the value returned by current-output-port.

6.7.4. System interface

Questions of system interface generally fall outside of the domain of this report. However, the following operations are important enough to deserve description here.

(load filename)  load module procedure
(include filename)  load module syntax

Filename should be a string naming an existing file containing Scheme source code. The load procedure reads expressions and definitions from the file and evaluates them
sequentially. It is unspecified whether the results of the expressions are printed. The load procedure does not affect the values returned by current-input-port and current-output-port. Load returns an unspecified value.

Include is similar to load except that it is syntax which expands into the expressions and definitions from the file. Thus it can be used to include internal definitions and otherwise interact with the current lexical scope. In an include form filename must be a string literal.

Rationale: For portability, load and include must operate on source files. Their operation on other kinds of files necessarily varies among implementations.

(file-exists? filename) file module procedure
Filename must be a string. The file-exists? procedure returns #t if the named file exists at the time the procedure is called, #f otherwise.

(delete-file filename) file module procedure
Filename must be a string. The delete-file procedure deletes the named file if it exists and can be deleted, and returns an unspecified value. If the file does not exist or cannot be deleted, an exception is raised.

(command-line) process-context module procedure
Returns the command line arguments passed to the process as a list of strings.

(get-environment-variable name) process-context module procedure
Name must be a string. Returns the value of the named environment variable as a string, or #f if the named environment variable is not found. get-environment-variable may use locale-setting information to encode the name and decode the value of the environment variable. If get-environment-variable can’t decode the value it may raise an exception.

(get-environment-variable "PATH")
⇒ "/usr/local/bin:/usr/bin:/bin"

(get-environment-variables) process-context module procedure
Returns the names and values of all the environment variables as an a-list, where the car of each entry is the name of an environment variable and the cdr is the value as would be returned by get-environment-variable. The order of the list is unspecified.
7. Formal syntax and semantics

This chapter provides formal descriptions of what has already been described informally in previous chapters of this report.

7.1. Formal syntax

This section provides a formal syntax for Scheme written in an extended BNF.

All spaces in the grammar are for legibility. Case is insignificant; for example, #x1A and #X1A are equivalent. (empty) stands for the empty string.

The following extensions to BNF are used to make the description more concise: (thing)* means zero or more occurrences of (thing); and (thing)+ means at least one (thing).

7.1.1. Lexical structure

This section describes how individual tokens (identifiers, numbers, etc.) are formed from sequences of characters. The following sections describe how expressions and programs are formed from sequences of tokens.

(Intertoken space) may occur on either side of any token, but not within a token.

Tokens which require implicit termination (identifiers, numbers, characters, and dot) may be terminated by any (delimiter), but not necessarily by anything else.

The following five characters from the ASCII repertoire are reserved for future extensions to the language: [ ] { } | |

In addition to the identifier characters of the ASCII repertoire specified below, Scheme implementations may permit any additional repertoire of Unicode characters to be employed in symbols (and therefore identifiers), provided that each such character has a Unicode general category of Lu, Lt, Lm, Lo, Mn, Mc, Me, Nd, Nl, No, Pd, Pc, Po, Sc, Sm, Sk, So, or Co, or is U+200C or U+200D (the zero-width non-joiner and joiner, respectively, which are needed for correct spelling in Persian, Hindi, and other languages). No non-Unicode characters may be used explicitly (that is, other than by specifying an escape) in symbols or identifiers.

All Scheme implementations must permit the sequence \x<hexdigits>; to appear in Scheme symbols (and therefore identifiers). If the character with the given Unicode scalar value is supported by the implementation, identifiers containing such a sequence are equivalent to identifiers containing the corresponding character. The symbol->string procedure may return the actual character or the escape sequence at the implementation's option, but any leading zeros must be removed from the escape sequence.

(token) → (identifier) | (boolean) | (number)
   | (character) | (string)
   | ( ) | # | \ | ^ | . | , | .
(delimiter) → (whitespace) | ( | ) | " | ;
(whitespace) → (space or newline)
(comment) → ; (all subsequent characters up to a line break)
   | (nested comment)
   | #; (atmosphere) (datum)
(nested comment) → #| (comment text)
   | (comment cont)* | #
(comment text) → (character sequence not containing #| or |#)
(comment cont) → (nested comment) (comment text)
(atmosphere) → (whitespace) | (comment)
(intertoken space) → (atmosphere)*

(identifier) → (initial) (subsequent)*
   | (vertical bar) (symbol element)* (vertical bar)
   | (peculiar identifier)
(initial) → (letter) | (special initial)
   | (inline hex escape)
(letter) → a | b | c | ... | z
   | A | B | C | ... | Z
(special initial) → ! | $ | % | & | * | | / | : | < | =
   | > | ? | - | -
(subsequent) → (initial) | (digit)
   | (special subsequent)
(digit) → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
(hex digit) → (digit)
   | a | A | b | B | c | C | d | D | e | E | f | F
(explicit sign) → + | -
(special subsequent) → (explicit sign) | . | @
(inline hex escape) → \x(hex scalar value);
(hex scalar value) → (hex digit)+
(peculiar identifier) → (explicit sign)
   | (explicit sign) (sign subsequent) (subsequent)*
   | (explicit sign) . (dot subsequent) (subsequent)*
   | . (non-digit) (subsequent)*
(non-digit) → (dot subsequent) | (explicit sign)
(dot subsequent) → (sign subsequent) | .
(sign subsequent) → (initial) | (explicit sign) | @
(symbol element) →
   | (any character other than (vertical bar) or \)
(syntactic keyword) → (expression keyword)
   | else | => | define
   | unquote | unquote-splicing
(expression keyword) → quote | lambda | if
   | set! | begin | cond | and | or | case
   | let | let* | letrec | do | delay
   | quasiquote
(variable) → (any (identifier) that isn't also a (syntactic keyword))
(boolean) → #t | #f
7.1.2. External representations

(Datum) is what the read procedure (section 6.7.2) successfully parses. Note that any string that parses as an (expression) will also parse as a (datum).

\[
7.1.3. Expressions
\]

(expression) \(
\rightarrow (\text{variable})
\]

<table>
<thead>
<tr>
<th>(literal)</th>
<th>(procedure call)</th>
<th>(lambda expression)</th>
<th>(condition)</th>
<th>(assignment)</th>
<th>(derived expression)</th>
<th>(macro use)</th>
<th>(macro block)</th>
</tr>
</thead>
</table>

\[
\text{(suffix)} \rightarrow (\text{empty})
\]

<table>
<thead>
<tr>
<th>(empty)</th>
<th>(digit)</th>
<th>(digit)</th>
</tr>
</thead>
</table>

\[
\text{(exponent marker)} \rightarrow (\text{e} | \text{s} | \text{f} | \text{d} | \text{l})
\]

\[
\text{(radix 2)} \rightarrow (\text{#b})
\]

\[
\text{(radix 8)} \rightarrow (\text{#o})
\]

\[
\text{(radix 16)} \rightarrow (\text{#x})
\]

\[
\text{(digit)} \rightarrow (0 | 1 | 2 | 3 | 4 | 5 | 6 | 7)
\]

\[
\text{(digit)} \rightarrow (\text{digit} | \text{a} | \text{b} | \text{c} | \text{d} | \text{e} | \text{f})
\]
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7.1.5. Transformers

\[
\text{(transformer spec)} \rightarrow \\
\text{\{syntax-rules (identifier)* (syntax rule)*\}}
\]

\[
\text{(syntax rule)} \rightarrow \\
\text{\{\langle pattern\}\ (template)\}}
\]

\[
\text{(pattern)} \rightarrow \\
\text{\{pattern identifier\}}
\]

\[
\text{\{pattern identifier\} \rightarrow \\
\text{\{underscore\}\}}
\]

\[
\text{\{underscore\} \rightarrow \\
\text{\{pattern\}+\}}
\]

\[
\text{\{pattern\} \rightarrow \\
\text{\{pattern\}\ (ellipsis)\ (pattern)*\}}
\]

\[
\text{\{pattern\}\ (ellipsis)\ (pattern)*\ \rightarrow \\
\text{\{pattern datum\}\}}
\]

\[
\text{\{pattern datum\} \rightarrow \\
\text{\{string\}}
\]

\[
\text{\{string\} \rightarrow \\
\text{\{character\}\}}
\]

\[
\text{\{character\} \rightarrow \\
\text{\{boolean\}\}}
\]

\[
\text{\{boolean\} \rightarrow \\
\text{\{number\}\}}
\]

\[
\text{\{number\} \rightarrow \\
\text{\{template\} (template)}
\]

\[
\text{\{template\} \rightarrow \\
\text{\{transformer spec\}\}}
\]

\[
\text{\{transformer spec\} \rightarrow \\
\text{\{keyword\} (datum)*\}}
\]

\[
\text{(keyword) \rightarrow \\
\text{(identifier)}
\]

\[
\text{\{identifier\} \rightarrow \\
\text{\{pattern\}\ (template)\}}
\]

\[
\text{\{template\} \rightarrow \\
\text{\{pattern identifier\}}
\]

\[
\text{\{pattern identifier\} \rightarrow \\
\text{\{template element\}+\}}
\]

\[
\text{\{template element\} \rightarrow \\
\text{\{template\}}
\]

\[
\text{\{template\} \rightarrow \\
\text{\{template element\}\ (template)}
\]

\[
\text{\{template\} \rightarrow \\
\text{\{pattern\}\ (pattern identifier\)}}
\]

\[
\text{\{pattern\}\ (pattern identifier\)} \rightarrow \\
\text{\{any identifier except \ldots\}}
\]

\[
\text{\{any identifier except \ldots\}} \rightarrow \\
\text{\{an identifier defaulting to \ldots\}}
\]

7.1.4. Quasiquotations

The following grammar for quasiquote expressions is not context-free. It is presented as a recipe for generating an infinite number of production rules. Imagine a copy of the following rules for \( D = 1, 2, 3, \ldots \) \( D \) keeps track of the nesting depth.

\[
\text{(quasiquotation)} \rightarrow \\
\text{(quasiquotation 1)}
\]

\[
\text{(qq template 0)} \rightarrow \\
\text{(expression)}
\]

\[
\text{(expression)} \rightarrow \\
\text{(case (expression))}
\]

\[
\text{(case clause)}^* \\
\text{(case clause)} \rightarrow \\
\text{(case clause)*}
\]

\[
\text{(else (sequence))} \\
\text{(else (sequence))}\rightarrow \\
\text{(else (sequence))*}
\]

\[
\text{(and test)*} \\
\text{(or test)*} \\
\text{(let (binding spec)* (body))} \\
\text{(let (variable) (binding spec)* (body))} \\
\text{(let* (binding spec)* (body))} \\
\text{(letrec (binding spec)* (body))} \\
\text{(letrec* (binding spec)* (body))} \\
\text{(begin (sequence))} \\
\text{(do (iteration spec)* (test) \{do result\} (command)*)} \\
\text{(delay (expression))} \\
\text{(quasiquotation)}
\]

\[
\text{(cond clause)} \rightarrow \\
\text{(test) (sequence)}
\]

\[
\text{(test) \rightarrow (recipient)}
\]

\[
\text{(receiver) \rightarrow (expression)}
\]

\[
\text{(case clause)} \rightarrow \\
\text{(\{datum\)* (sequence)\}}
\]

\[
\text{(\{datum\)* \{recipient\)} \rightarrow (expression)
\]

\[
\text{(binding spec)} \rightarrow \\
\text{(\{variable\) (expression))}
\]

\[
\text{(iteration spec)} \rightarrow \\
\text{(\{variable\) (\{init\) (\{step\))}
\]

\[
\text{(\{variable\) (\{init\)) \rightarrow (expression)}
\]

\[
\text{(step) \rightarrow (expression)}
\]

\[
\text{(do result) \rightarrow (sequence) | (empty)}
\]

\[
\text{(macro use) \rightarrow (\{keyword\) (\{datum\)*\}}
\]

\[
\text{(keyword) \rightarrow (identifier)}
\]

\[
\text{(macro block) \rightarrow \\
\text{(let-syntax (syntax spec)* (body))}
\]

\[
\text{(let-rec-syntax (syntax spec)* (body))}
\]

\[
\text{(syntax spec) \rightarrow (\{keyword\) (\transformer\ spec))}
\]

\[
\text{(quasiquote D) \rightarrow \{\{qq template D\}\}}
\]

\[
\text{(qq template D) \rightarrow (simple datum)}
\]

\[
\text{(list qq template D) \rightarrow (\{qq template D\})}
\]

\[
\text{(vector qq template D) \rightarrow (\{qq template D\})}
\]

\[
\text{(unquote D) \rightarrow (\{qq template D\})}
\]

\[
\text{(list qq template D) \rightarrow (\{qq template or splice D\)*\}}
\]

\[
\text{(\{qq template or splice D\)* \{qq template D\})}
\]

\[
\text{\{qq template D\}}
\]

\[
\text{(quasiquotation D + 1) \rightarrow (\{qq template D\})}
\]

\[
\text{(vector qq template D) \rightarrow \#(\{qq template or splice D\)*\}}
\]

\[
\text{(unquote \{qq template D - 1\}) \rightarrow (\{qq template D\})}
\]

\[
\text{(splicing unquotation D) \rightarrow \\{qq template D\}}
\]

\[
\text{(splicing unquotation D) \rightarrow \{qq template D\}}
\]

\[
\text{(unquote-splicing \{qq template D\})}
\]

In (quasiquotation)s, a \{list qq template D\} can sometimes be confused with either an (unquotation D) or a (splicing unquotation D). The interpretation as an (unquotation) or (splicing unquotation D) takes precedence.
7.1.6. Programs and definitions

(program) → (command or definition)*
(command or definition) → (command)
  | (definition)
  | (syntax definition)
  | (import (import set)+)
  | (begin (command or definition)+)
(definition) → (define (variable) (expression))
  | (begin (command or definition)+)
  | (cond-expand clause)
  | (module declaration)
  | (module name part)
(define-record-type (variable)
  | (constructor) (variable) (field spec)*
  | (begin (definition)*)
(def formals) → (variable)*
  | (variable)*
  | (variable)
(define (variable) (def formals) (body))
(define-record-type (variable)
  | (constructor) (variable) (field spec)*
  | (begin (definition)*)
(module) → (module name) (module declaration)*)
(module name) → ((module name part)+)
(module name part) → (identifier) | (integer 10)
(module declaration) → (export (export spec)*)
  | (import (import set)*)
  | (begin (command or definition)+)
  | (include (string)+)
  | (include-ci (string)+)
  | (cond-expand (cond-expand clause)*)
  | (cond-expand (cond-expand clause)*)
  | (begin (module declaration)*)
(export spec) → (identifier)
  | (rename (identifier) (identifier))
(import set) → (module name)
  | (only (import set) (identifier)+)
  | (except (import set) (identifier)+)
  | (prefix (import set) (identifier))
  | (rename (import set) (export spec)+)
(cond-expand clause) →
  | ((feature requirement) (module declaration)*)
(feature requirement) → (identifier)
  | (module name)
  | (and (feature requirement)*)
  | (or (feature requirement)*)
  | (not (feature requirement))

7.2. Formal semantics

This section provides a formal denotational semantics for
the primitive expressions of Scheme and selected built-in
procedures. The concepts and notation used here are
described in [31]; the notation is summarized below:

(…) sequence formation
s ↓ k kth member of the sequence s (1-based)
#s length of sequence s
s ⊢ t concatenation of sequences s and t
s ↑ k drop the first k members of sequence s
t → a, b McCarthy conditional “if t then a else b”
r[x/i] substitution “r with x for i”
x ∈ D injection of x into domain D
x | D projection of x to domain D

The reason that expression continuations take sequences
of values instead of single values is to simplify the formal
treatment of procedure calls and multiple return values.
The boolean flag associated with pairs, vectors, and strings
will be true for mutable objects and false for immutable
objects.

The order of evaluation within a call is unspecified. We
mimic that here by applying arbitrary permutations
permute and unpermute, which must be inverses, to the
arguments in a call before and after they are evaluated. This
is not quite right since it suggests, incorrectly, that the order
of evaluation is constant throughout a program (for any
given number of arguments), but it is a closer approximation
to the intended semantics than a left-to-right evaluation
would be.

The storage allocator new is implementation-dependent,
but it must obey the following axiom: if new σ ∈ L, then
σ (new σ | L) ↓ 2 = false.

The definition of K is omitted because an accurate definition
of K would complicate the semantics without being very
interesting.

If P is a program in which all variables are defined before
being referenced or assigned, then the meaning of P is

\[ \mathcal{E}[[(\lambda (\text{I}^*) (P^*)) (\text{undefined}) \ldots]] \]

where I* is the sequence of variables defined in P, P' is the
sequence of expressions obtained by replacing every defini-
tion in P by an assignment, (undefined) is an expression
that evaluates to undefined, and \( \mathcal{E} \) is the semantic function
that assigns meaning to expressions.
7.2.1. Abstract syntax

- **K** ∈ **Con** constants, including quotations
- **I** ∈ **Ide** identifiers (variables)
- **E** ∈ **Exp** expressions
- **Γ** ∈ **Com** = **Exp** commands

\[ \text{Exp} \rightarrow K \mid I \mid (E_0 \ E^*) \]

\[ | \text{(lambda } (I^*) \, \Gamma^* \, E_0) \]

\[ | \text{(lambda } (I^* \cdot I) \, \Gamma^* \, E_0) \]

\[ | \text{(lambda } I \, \Gamma^* \, E_0) \]

\[ | \text{(if } E_0 \ E_1 \ E_2) \mid \text{(if } E_0 \ E_1) \]

\[ | \text{set! } I \ E \]

7.2.2. Domain equations

\[ \alpha \in L \] locations

\[ \nu \in \mathbb{N} \] natural numbers

\[ T = \{ \text{false, true} \} \] booleans

\[ Q \] symbols

\[ H \] characters

\[ R \] numbers

\[ E_p = L \times L \times T \] pairs

\[ E_v = L^* \times T \] vectors

\[ E_s = L^* \times T \] environment stores

\[ M = \{ \text{false, true, null, undefined, unspecified} \} \] miscellaneous

\[ \phi \in F = L \times (E^* \to K \to C) \] procedure values

\[ \epsilon \in E = Q + H + R + E_p + E_v + E_s + M + F \] expressed values

\[ \sigma \in S = L \to (E \times T) \] stores

\[ \rho \in U = \text{Ide} \to L \] environments

\[ \theta \in C = S \to A \] command continuations

\[ \kappa \in K = E^* \to C \] expression continuations

\[ A \] answers

\[ X \] errors

7.2.3. Semantic functions

\[ \mathcal{K} : \text{Con} \to \mathbb{E} \]

\[ \mathcal{E} : \text{Exp} \to \mathbb{U} \to K \to C \]

\[ \mathcal{E}^* : \text{Exp}^* \to \mathbb{U} \to K \to C \]

\[ \mathcal{C} : \text{Com}^* \to \mathbb{U} \to C \to C \]

Definition of \( \mathcal{K} \) deliberately omitted.

\[ \mathcal{E}[K] = \lambda \rho \cdot \text{send}(\mathcal{K}[K]) \kappa \]

\[ \mathcal{E}[I] = \lambda \rho \cdot \text{hold}(\text{lookup } \rho \ I) \]

\[ (\text{single}(\lambda \epsilon \cdot \epsilon = \text{undefined} \rightarrow \text{wrong “undefined variable”}, \text{send } \epsilon \kappa)) \]

\[ \mathcal{E}[(E_0 \ E^*)] = \lambda \rho \cdot \mathcal{E}^*(\text{permute}((E_0) \ E^*)) \]

\[ \mathcal{E}[(\mathbb{I} \ E^*)] = \lambda \rho \cdot (\lambda \epsilon \cdot \text{applicate}(\epsilon \downarrow 1) (\epsilon \uparrow 1) \kappa) \text{ (unpermute } \epsilon)) \]

\[ \mathcal{E}[(\text{lambda } (I^*) \, \Gamma^* \, E_0)] = \lambda \rho \cdot \lambda \sigma \cdot \lambda \epsilon \cdot \text{send}(\text{new } \sigma \in L \rightarrow \text{send}(\text{new } \sigma \mid L, \lambda \epsilon \cdot \text{tienvalsrest}(\lambda \epsilon \cdot \mathcal{C}[\Gamma^* \rho \mathcal{E}[E_0] \rho \kappa)' ) (\text{extends } \rho \Gamma^* \alpha^*)) \text{, wrong “wrong number of arguments”) in } E) \]

\[ \mathcal{E}[(\text{lambda } (I^* \cdot I) \, \Gamma^* \, E_0)] = \lambda \rho \cdot \lambda \sigma \cdot \lambda \epsilon \cdot \text{send}(\text{new } \sigma \in L \rightarrow \text{send}(\text{new } \sigma \mid L, \lambda \epsilon \cdot \text{tienvalsrest}(\lambda \epsilon \cdot \mathcal{C}[\Gamma^* \rho \mathcal{E}[E_0] \rho \kappa)' ) (\text{extends } \rho \Gamma^* \alpha^*)) \text{, wrong “too few arguments”) in } E) \]

\[ \kappa \text{, wrong “out of memory”) } \sigma \]

\[ \mathcal{E}[(\text{lambda } I \, \Gamma^* \, E_0)] = \mathcal{E}[(\text{lambda } (\cdot) \, \Gamma^* \, E_0)] \]

\[ \mathcal{E}[(\text{if } E_0 \ E_1 \ E_2)] = \lambda \rho \cdot \mathcal{E}[E_0] \rho (\text{single}(\lambda \epsilon \cdot \text{truish } \epsilon \rightarrow \mathcal{E}[E_1] \rho \kappa, \mathcal{E}[E_2] \rho \kappa)) \]

\[ \mathcal{E}[(\text{if } E_0 \ E_1)] = \lambda \rho \cdot \mathcal{E}[E_0] \rho (\text{single}(\lambda \epsilon \cdot \text{truish } \epsilon \rightarrow \mathcal{E}[E_1] \rho \kappa, \text{send unspecified } \kappa)) \]

Here and elsewhere, any expressed value other than **undefined** may be used in place of **undefined**.
lookup : U → Ide → L
lookup = \lambda \alpha . \rho
extends : U → Ide* → L* → U
extends = 
\lambda \rho^{*} \cdot \#^{*} = 0 \rightarrow \rho, 
extends (\rho (\alpha \cdot \downarrow 1) / (\alpha^{*} \downarrow 1)) (\alpha^{*} \downarrow 1) (\alpha^{*} \downarrow 1)

wrong : X → C  [implementation-dependent]
send : E → K → C
send = \lambda \epsilon . \kappa (\epsilon)
single : (E → C) → K
single =
\lambda \psi . \# \epsilon = 1 \rightarrow \psi (\epsilon \downarrow 1),
wrong “wrong number of return values”

new : S → (L + \{ error\})  [implementation-dependent]
hold : L → K → C
hold = \lambda \alpha \kappa . send (\sigma \downarrow 1) \kappa
assign : L → E → C → S
assign = \lambda \alpha \theta . \theta (update \alpha \sigma)
update : L → E → S → S
update = \lambda \alpha \sigma . \sigma (\epsilon, true) / \alpha

tievals : (L* → C) → E* → C
tievals =
\lambda \psi \sigma . \# \epsilon = 0 \rightarrow \psi (\sigma),
new \sigma ∈ L → tievals (\lambda \alpha . \psi ((\new \sigma | L) \| \alpha^{*}))
(\epsilon^{*} \downarrow 1)
(update (\new \sigma | L) (\epsilon^{*} \downarrow 1) \sigma),
wrong “out of memory” \sigma
	ievalsrest : (L* → C) → E* → N → C
tievalsrest =
\lambda \psi \epsilon . \list (\dropfirst e \nu)
(singe (\lambda \epsilon . tievals (\takefirst e \nu) (\| \epsilon)))
dropfirst = \lambda \ln . n = 0 → l, dropfirst (l \uparrow 1) (n - 1)
takefirst = \lambda \ln . n = 0 → \langle, (l \downarrow 1) (\| \takefirst (l \uparrow 1) (n - 1))

trush : E → T
trush = \lambda \epsilon . \epsilon = false → false, true

permute : Exp* → Exp*  [implementation-dependent]
unpermute : E* → E*  [inverse of permute]
apply : E → E* → K → C
apply =
\lambda \epsilon . \kappa . \epsilon ∈ F \rightarrow (\epsilon I) \epsilon \kappa, wrong “bad procedure”
onearg : (E → K → C) → (E* → K → C)
onearg =
\lambda \epsilon \kappa . \# \epsilon = 1 \rightarrow \epsilon (\epsilon \downarrow 1) \kappa,
wrong “wrong number of arguments”
twoarg : (E → E → K → C) → (E* → K → C)
twoarg =
\lambda \epsilon \kappa . \# \epsilon = 2 \rightarrow \epsilon (\epsilon \downarrow 1) (\epsilon \downarrow 2) \kappa,
wrong “wrong number of arguments”

list : E* → K → C
list =
\lambda \epsilon . \kappa . \# \epsilon = 0 \rightarrow (\null \kappa,
list (\epsilon \uparrow 1) ( single (\lambda \epsilon . cons (\epsilon \downarrow 1, \epsilon) \kappa))
cons : E* → K → C
cons =
twoarg (\lambda \epsilon \sigma . \new \sigma ∈ L →
(\lambda \sigma' . \new \sigma' ∈ L →
send ((\new \sigma | L, \sigma') | L, true)
in E)
κ
(update (\new \sigma | L) \sigma'),
wrong “out of memory” \sigma)
(update (\new \sigma | L) \sigma),
wrong “out of memory” \sigma)

less : E* → K → C
less =
twoarg (\lambda \epsilon \sigma . \epsilon ∈ E_0 →
send (\epsilon | E_0, false \kappa),
wrong “non-numeric argument to <”)
add : E* → K → C
add =
twoarg (\lambda \epsilon \sigma . \epsilon ∈ E_0 →
send ((\epsilon | R + \epsilon | R) in E) \kappa,
wrong “non-numeric argument to +”)
7.3. Derived expression types

This section gives macro definitions for the derived expression types in terms of the primitive expression types (literal, variable, call, lambda, if, set!). See section 6.4 for a possible definition of delay.

\begin{verbatim}
(define-syntax cond
  (syntax-rules (else =>)
    ((cond (else result1 result2 ...))
     (begin result1 result2 ...))
    ((cond (test => result))
     (let ((temp test))
      (if temp (result temp))))
    ((cond (test => result) clause1 clause2 ...)
     (let ((temp test))
      (if temp (result temp)
        (cond clause1 clause2 ...))))
    ((cond (test result1 result2 ...))
     (if test (begin result1 result2 ...))
      (cond clause1 clause2 ...))
    ((cond (test result1 result2 ...) clause1 clause2 ...)
     (if test (begin result1 result2 ...) (cond clause1 clause2 ...))))

(define-syntax case
  (syntax-rules (else =>)
    ((case (key ...) clauses ...)
     (let ((atom-key (key ...))
        (case atom-key clauses ...)))
    ((case key (else => result))
     (result key))
    ((case key (else result1 result2 ...))
     (begin result1 result2 ...))
    ((case key (atoms ...) result1 result2 ...)
     (if (memv key '(atoms ...)) (begin result1 result2 ...))
      (case key (atoms ...) result1 result2 ...))
    ((case key (atoms ...) => result)
     (if (memv key '(atoms ...)) (result key))
      (case key (atoms ...) => result)
      (case key (atoms ...) => result clause clauses ...))
    ((case key (atoms ...) => result)
     (if (memv key '(atoms ...)) (result key))
      (case key (atoms ...) => result)
      (case key (atoms ...) => result clause clauses ...)))

(define-syntax and
  (syntax-rules ()
    ((and) #t)
    ((and test) test)
    ((and test1 test2 ...) (if test1 (and test2 ...) #f))))

(define-syntax or
  (syntax-rules ()
    ((or) #f)
    ((or test) test)
    ((or test1 test2 ...) (if test1 (and test2 ...) #f))))

(define-syntax and
  (syntax-rules ()
    ((and) #t)
    ((and test) test)
    ((and test1 test2 ...) (if test1 (and test2 ...) #f))))

(define-syntax or
  (syntax-rules ()
    ((or) #f)
    ((or test) test)
    ((or test1 test2 ...) (if test1 (and test2 ...) #f))))
\end{verbatim}
(define-syntax let
  (syntax-rules ()
    ((let ((name val) ...) body1 body2 ...) body1 body2 ...)
    ((lambda (name ...) body1 body2 ...) val ...)
    ((let tag ((name val) ...) body1 body2 ...) (let tag ((tag (lambda (name ...) body1 body2 ...))) val ...))
    ((let* () body1 body2 ...) (let () body1 body2 ...))
    ((let* ((name1 val1) (name2 val2) ...) body1 body2 ...) (let ((name1 val1)) (let* ((name2 val2) ...) body1 body2 ...)))
    ((letrec ((var1 init1) ...) body ...) body ...))
  (define-syntax letrec*
    (syntax-rules ()
      ((letrec* ((var1 init1) ...) body1 body2 ...) body1 body2 ...)
      ((begin exp ...) (begin exp ...))))
  (define-syntax begin
    (syntax-rules ()
      ((begin exp) exp)
      ((begin exp1 exp2 ...) (let ((x exp1)) (begin exp2 ...))))
  (define-syntax do
    (syntax-rules ()
      ((do ((var init step ...) ...) (test expr ...) command ...) command ...)
      ((do "step" x y) (loop init ...))
      ((do "step" x) x)
      ((do "step" x y) y))
  (define-syntax begin
    (syntax-rules ()
      ((begin exp) exp)
      ((begin exp1 exp2 ...) (let ((x exp1)) (begin exp2 ...))))
  The following alternative expansion for begin does not make use of the ability to write more than one expression in the body of a lambda expression. In any case, note that these rules apply only if the body of the begin contains no definitions.
  (define-syntax do
    (syntax-rules ()
      ((do ((var init step ...) ...) (test expr ...) command ...) command ...)
      ((do "step" x y) (loop init ...))
      ((do "step" x) x)
      ((do "step" x y) y))
  (define-syntax begin
    (syntax-rules ()
      ((begin exp) exp)
      ((begin exp1 exp2 ...) (let ((x exp1)) (begin exp2 ...))))
  The following definition of do uses a trick to expand the variable clauses. As with letrec above, an auxiliary macro would also work. The expression (if #f #f) is used to obtain an unspecific value.
  (define-syntax do
    (syntax-rules ()
      ((do ((var init step ...) ...) (test expr ...) command ...) command ...)
      ((do "step" x y) (loop init ...))
      ((do "step" x) x)
      ((do "step" x y) y))
  The following alternative expansion for begin does not make use of the ability to write more than one expression in the body of a lambda expression. In any case, note that these rules apply only if the body of the begin contains no definitions.
  (define-syntax begin
    (syntax-rules ()
      ((begin exp) exp)
      ((begin exp1 exp2 ...) (let ((x exp1)) (begin exp2 ...))))
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  (define-syntax do
    (syntax-rules ()
      ((do ((var init step ...) ...) (test expr ...) command ...) command ...)
      ((do "step" x y) (loop init ...))
      ((do "step" x) x)
      ((do "step" x y) y))
  The following alternative expansion for begin does not make use of the ability to write more than one expression in the body of a lambda expression. In any case, note that these rules apply only if the body of the begin contains no definitions.
  (define-syntax begin
    (syntax-rules ()
      ((begin exp) exp)
      ((begin exp1 exp2 ...) (let ((x exp1)) (begin exp2 ...))))
  The following definition of do uses a trick to expand the variable clauses. As with letrec above, an auxiliary macro would also work. The expression (if #f #f) is used to obtain an unspecific value.
  (define-syntax do
    (syntax-rules ()
      ((do ((var init step ...) ...) (test expr ...) command ...) command ...)
      ((do "step" x y) (loop init ...))
      ((do "step" x) x)
      ((do "step" x y) y))
Appendix A. Standard Modules

This section lists the exports provided by the standard modules. The modules are factored so as to separate features which may not be supported by all implementations, or which may be expensive to load.

The scheme module prefix is used for all standard modules, and is reserved for use by future standards.

Base Module

The (scheme base) module exports many of the procedures and syntax bindings that are traditionally associated with Scheme.

* + -
/ <= <
=> = >=
> abs and
append apply assoc
assq assv begin
boolean? blob-length blob-u8-ref
blob-u8-set! blob? caar
cadr call-with-current-continuation
call/cc car case-lambda
case cdddar cdddr
cdr ceiling char->integer
car-char-alphabetic? char-lower-case? char-numeric?
car-upper-case? char-whitespace? char<=?
car>? char? complex?
cond cons copy-blob!
copy-blob! copy-partial-blob!
copy-blob copy-blob! copy-vector
copy-vector define-syntax
define define-record-type
define-define-record-type
denominator display do
dynamic-wind eq? equal?
eqv? error even?
exact->inexact exact->integer
exact-integer? exact? exp
floor for-each gcd
guard if import
include inexact->exact inexact?
integer->char integer? lambda
lcm length let*
let-syntax letrec* letrec-syntax
letrec let list->string
list->vector list-ref list-set!
list-tail list? list
make-blob make-list make-parameter
make-string make-vector map
max member memq
memv min modulo
negative? newline nil
not null? number->string
number? numerator odd?
or pair? parameterize
partial-blob positive? procedure?
quasiquote quote quotient
raise-continuable raise
rational? rationalize real?
remainder reverse round
set! set-car! set-cdr!
string->list string->number set->cdr!
string->vector string-append string-copy
string-fill! string-for-each string-set!
string-map string-ref string-length
string=? string<=? string>=?
string string->list string->symbol
string->vector string-append string-copy
string-fill! string-for-each string-length
string-map string-ref string-set!
string<=? string<? string=?
string>=? string>? string?
substring symbol->string
symbol? syntax-error syntax-rules
truncate vector->list vector->string
vector-fill! vector-for-each vector-length
vector-map vector-ref vector-set!
vector? vector zero?
with-exception-handler

Repl Module
The (scheme repl) module exports the interaction-environment procedure.

Inexact Module
The (scheme inexact) module exports procedures which are typically only useful with inexact values.

exp log sqrt
sin cos tan
asin acos atan
finite? infinite? nan?

Complex Module
The (scheme complex) module exports procedures which are typically only useful with complex values.

angle magnitude imag-part real-part
make-polar make-rectangular

Division Module
The (scheme division) module exports procedures for integer division.

floor/ ceiling/ truncate/ round/ euclidean/
floor-quotient ceiling-quotient truncate-quotient round-quotient euclidean-quotient
floor-remainder ceiling-remainder truncate-remainder round-remainder euclidean-remainder

Lazy Module
The (scheme lazy) module exports forms for lazy evaluation.

delay force

Eval Module
The (scheme eval) module exports procedures for evaluating Scheme data as programs.

eval
null-environment
scheme-report-environment

Load Module
The (scheme load) module exports forms for loading and including Scheme expressions from files.

load include

Multiple Values Module
The (scheme multiple-values) module exports procedures for generating and receiving multiple values.

call-with-value values

I/O Module
The (scheme io) module exports procedures for general input and output on ports.

binary-port? character-port?
close-input-port current-error-port
close-output-port get-output-string
eof-object? newline
input-port? open-input-string
output-port? peek-char
peek-u8? port?
read-char read-u8
read-ready? write-char
write-u8

File Module
The (scheme file) module provides procedures for accessing files.

call-with-input-file call-with-output-file
delete-file file-exists?
open-input-file open-output-file
with-input-from-file with-output-to-file

Read Module
The (scheme read) module provides procedures for reading Scheme objects.
The \((\text{scheme write})\) module provides procedures for writing Scheme objects.

\textbf{Unicde Module}

The \((\text{scheme unicode})\) module provides procedures for dealing with Unicode case conversions and normalization.

\begin{verbatim}
char-ci=? char-ci<? char-ci>?
char-ci<=? char-ci>=? char-upcase
char-downcase char-foldcase string-ci=?
string-ci<? string-ci=? string-ci>?
string-ci<=? string-ci>=? string-ni<?
string-ni<=? string-ni>=? string-ni>?
string-upcase string-downcase string-foldcase
\end{verbatim}

\textbf{Time}

The \((\text{scheme time})\) module provides access to the system time.

\begin{verbatim}
current-posix-second
current-jiffy
jiffies-per-second
\end{verbatim}
<table>
<thead>
<tr>
<th>Feature identifier</th>
<th>Feature description</th>
</tr>
</thead>
<tbody>
<tr>
<td>r7rs</td>
<td>All R7RS Scheme implementations have this feature.</td>
</tr>
<tr>
<td>exact-closed</td>
<td>All rational operations except / produce exact values given exact inputs.</td>
</tr>
<tr>
<td>ratios</td>
<td>/ with exact arguments produces an exact result when the divisor is nonzero.</td>
</tr>
<tr>
<td>ieeefloat</td>
<td>Inexact numbers are IEEE 754 floating point values.</td>
</tr>
<tr>
<td>full-unicode</td>
<td>All Unicode characters are supported.</td>
</tr>
<tr>
<td>windows</td>
<td>This Scheme implementation is running on Windows.</td>
</tr>
<tr>
<td>posix</td>
<td>This Scheme implementation is running on a Posix system.</td>
</tr>
<tr>
<td>unix, darwin, linux, bsd, freebsd, solaris, ...</td>
<td>Operating system flags (more than one may apply).</td>
</tr>
<tr>
<td>i386, x86-64, ppc, sparc, jvm, cl, llvm, ...</td>
<td>CPU architecture flags.</td>
</tr>
<tr>
<td>ilp32, lp64, ilp64, ...</td>
<td>C memory model flags.</td>
</tr>
<tr>
<td>big-endian, little-endian</td>
<td>Byte order flags.</td>
</tr>
<tr>
<td>⟨name⟩</td>
<td>The name of this implementation.</td>
</tr>
<tr>
<td>⟨name-version⟩</td>
<td>The name and version of this implementation.</td>
</tr>
</tbody>
</table>

Table B.1: Standard Feature Identifiers

NOTES

Language changes

This section enumerates the changes that have been made to Scheme since the “Revised\(^5\) report” [2] was published.

While this report is in draft status the list should be considered incomplete and subject to change.

- Modules have been added as a new program structure to improve encapsulation and sharing of code. Some existing and new identifiers have been factored out into separate modules.
- Exceptions can now be signalled explicitly with `raise`, `raise-continuable` or `error`, and can be handled with `with-exception-handler` and the `guard` syntax.
- New disjoint types supporting access to multiple fields can be generated with `define-record-type`.
- Parameter objects can be created with `make-parameter`, and dynamically rebound with `parameterize`.
- Blobs, homogeneous vectors of integers in the range \([0..255]\), have been added as a new disjoint type.
- Ports can now be designated as `binary` or `character` ports, with new procedures for reading and writing binary data.
- String ports have been added as a way to write characters to and read characters from strings.
- Current-input-port and current-output-port are now parameter objects, along with the newly introduced `current-error-port`.
- Syntax-rules now recognizes , as a wildcard, allows the ellipsis symbol to be specified explicitly instead of the default ,..., allows template escapes with an ellipsis-prefixixed list, and allows tail patterns to follow an ellipsis pattern.
- Syntax-error has been added as a way to signal immediate and more informative errors when a form is expanded.
- Internal `define-syntax` forms are now allowed preceding any internal `defines`.
- Letrec* has been added, and internal define specified in terms of it.
- Case now supports a =⇒ syntax analogous to `cond`.
- Case-lambda has been added to the base library as a way to dispatch on the number of arguments passed to a procedure.
- Positive and negative infinity and a NaN object have been added to the numeric tower as inexact values with the written representations `+inf.0`, `-inf.0` and `+nan.0`, respectively.
- Map and `for-each` are now required to terminate on the shortest list when inputs have different length.
- Member and `assoc` now take an optional third argument for the equality predicate to use.
- Exact-integer? and `exact-integer-sqrt` have been added.
- Make-list, `copy-list`, `list-set!`, `string-map`, `string-for-each`, `string->vector`, `copy-vector`, `vector-map`, `vector-for-each`, and `vector->string` have been added to round out the sequence operations.
The set of characters used is required to be consistent with the latest Unicode standard only in so far as the implementation supports Unicode.

`string-ni=?` and related procedures have been added to compare strings as though they had gone through an implementation-defined normalization, without exposing the normalization.

The case-folding behavior of the reader can now be explicitly controlled, with no folding as the default.

The reader now recognizes the new comment syntax `#;` to skip the next datum, and allows nested block comments with `#| ... |#`.

Data prefixed with reader labels `<n>` can be referenced with `<n>` allowing for reading and writing of data with shared structure.

Strings and symbols now allow mnemonic and numeric escape sequences, and the list of named characters has been extended.

`File-exists?` and `delete-file` are available in the (scheme file) module.

An interface to the system environment and command line is available in the (scheme process-context) module.

Procedures for accessing the current time are available in the (scheme time) module.

A complete set of integer division operators is available in the (scheme division) module.

`Transcript-on` and `transcript-off` have been removed.

**ADDITIONAL MATERIAL**

The Internet Scheme Repository at

http://www.cs.indiana.edu/scheme-repository/

contains an extensive Scheme bibliography, as well as papers, programs, implementations, and other material related to Scheme.

The Scheme community website at

http://schemers.org/

contains additional resources for learning and programming, job and event postings, and Scheme user group information.

---

**EXAMPLE**

`Integrate-system` integrates the system

\[
y'_k = f_k(y_1, y_2, \ldots, y_n), \quad k = 1, \ldots, n
\]

differential equations with the method of Runge-Kutta. The parameter `system-derivative` is a function that takes a system state (a vector of values for the state variables \(y_1, \ldots, y_n\)) and produces a system derivative (the values \(y'_1, \ldots, y'_n\)). The parameter `initial-state` provides an initial system state, and \(h\) is an initial guess for the length of the integration step.

The value returned by `integrate-system` is an infinite stream of system states.

```scheme
(define integrate-system
  (lambda (system-derivative initial-state h)
    (let ((next (runge-kutta-4 system-derivative h)))
      (letrec ((states
                    (cons initial-state
                           (delay (map-streams next states)))))
        states))))
```

`Runge-Kutta-4` takes a function, \(f\), that produces a system derivative from a system state. `Runge-Kutta-4` produces a function that takes a system state and produces a new system state.

```scheme
(define runge-kutta-4
  (lambda (f h)
    (let ((*h (scale-vector h))
          (*2 (scale-vector 2))
          (*1/2 (scale-vector (/ 1 2)))
          (*1/6 (scale-vector (/ 1 6))))
      (lambda (y)
        ;; y is a system state
        (let* ((k0 (*h (f y)))
               (k1 (*h (f (add-vectors y (*1/2 k0)))))
               (k2 (*h (f (add-vectors y (*1/2 k1)))))
               (k3 (*h (f (add-vectors y k2)))))
            (add-vectors y
                         (*1/6 (add-vectors k0
                                  (*2 k1)
                                  (*2 k2)
                                  k3)))))))
```

`Elementwise` function:

```scheme
(define elementwise
  (lambda (f)
    (lambda vectors
      (generate-vector
       (vector-length (car vectors))
       (lambda (i)
         (apply f
                (map (lambda (v) (vector-ref v i))
                     vectors)))))))
```

`Generate-vector` function:

```scheme
(define generate-vector
  (lambda (size proc)
    ...))
```
(let ((ans (make-vector size)))
   (letrec ((loop
                (lambda (i)
                  (cond ((= i size) ans)
                        (else
                         (vector-set! ans i (proc i))
                         (loop (+ i 1)))))))
    (loop 0))))

(define add-vectors (elementwise +))

(define scale-vector
  (lambda (s)
    (elementwise (lambda (x) (* x s)))))

Map-streams is analogous to map: it applies its first argument (a procedure) to all the elements of its second argument (a stream).

(define map-streams
  (lambda (f s)
    (cons (f (head s))
          (delay (map-streams f (tail s))))))

Infinite streams are implemented as pairs whose car holds the first element of the stream and whose cdr holds a promise to deliver the rest of the stream.

(define head car)
(define tail
  (lambda (stream) (force (cdr stream))))

The following illustrates the use of integrate-system in integrating the system

$$C \frac{dv_C}{dt} = -i_L - \frac{v_C}{R}$$

$$L \frac{di_L}{dt} = v_C$$

which models a damped oscillator.

(define damped-oscillator
  (lambda (R L C)
    (lambda (state)
      (let ((Vc (vector-ref state 0))
            (Il (vector-ref state 1)))
        (vector (- 0 (+ (/ Vc (+ R C)) (/ Il C))
                 (/ Vc L))))))

(define the-states
  (integrate-system
    (damped-oscillator 10000 1000 .001)
    '#(1 0)
    .01))

REFERENCES


**ALPHABETIC INDEX OF DEFINITIONS OF CONCEPTS, KEYWORDS, AND PROCEDURES**

The principal entry for each term, procedure, or keyword is listed first, separated from the other entries by a semicolon.

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