Vars vs. constants
which-kwrt

the → to

bit-string
⇒ bit-vector

CARNEGIE-MELLON UNIVERSITY

DEPARTMENT OF COMPUTER SCIENCE

SPICE PROJECT

Common Lisp Reference Manual

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FLET LABELS ?

Annotations by Guy Steele (in multiple colors)

Flatiron Edition
Still a Few Odd Wrinkles Left

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Apology

For reasons unknown, Xerox has chosen not to provide any font for the Dover which faithfully reflects the ASCII standard. More precisely, there appears to be no simple way to get correct printed representations of the 95 standard ASCII printing characters. Many fonts do not have an accent grave; in other the accent grave is identical in appearance to the accent acute. Most fonts have a swung dash in place of the tilde, an uparrow or caret in place of the circumflex, and/or a leftarrow in place of the underscore.

This edition uses the SAILA family of Dover fonts for code. At CMU, at least, SAILA suffers from the swung-dash deficiency, and the accents acute and grave are not symmetric. The swung-dash problem has been compensated for by a SCRIBE macro.

Underscore !!

For reference, here are the 95 ASCII printing characters (the first is the space character) as they appear in the code font in this edition:

```
 !"#$%&'()*+,-./0123456789:;<=>?
@ABCDEFGHIJKLMNOPQRSTUVWXYZ[\]^_
`abcdefghijklmnopqrstuvwxyz{|}~
```

foo

—Guy L. Steele Jr.

Notes to the Swiss Cheese Edition

This edition is incredibly unpolished. It suffers from the following known deficiencies:

- The chapter on macros and `defmacro` is not yet written.
- The chapter on the evaluator is not yet written.
- The chapter on how programs are expressed as S-expressions (which includes `defun`, `defvar`, `defconst`, and so on) is not yet written.
- There is no coherent description of `setf` and related special forms.
- Nothing is yet written on packages and `intern`.
- No single entire pass has been made yet to catch inconsistencies.

Please send remarks, corrections, and criticisms to `Guy.Steele@CMUA`.

Chapter 1

INTRO

1.1. Purpose

This manual documents a dialect of LISP called "COMMON LISP", which is intended to meet these goals:

Commonality. At least four implementation groups already actively at work on LISP implementations for various machines are considering supporting this dialect. While the differing implementation environments will of necessity force incompatibilities among the implementations, nevertheless COMMON LISP can serve as a common dialect of which each implementation can be an upward-compatible superset.

Portability. COMMON LISP intentionally excludes features which cannot easily be implemented on a broad class of machines.

On the one hand, features which are difficult or expensive to implement on hardware without special microcode are avoided or provided in a more abstract and efficiently implementable form. (Examples of this are the forwarding (invisible) pointers and locatives of Lisp Machine LISP. Some of the problems which they solve are addressed in different ways in COMMON LISP.)

On the other hand, features which are useful only on certain "ordinary" or "commercial" processors are avoided or made optional. (An example of this is the type declaration facility, which is useful in some implementations and completely ignored in others; such declarations are completely optional and affect only efficiency, never semantics.)

Moreover, attention has been paid to making it easy to write programs in such a way as to depend as little as possible on machine-specific characteristics such as word length, while allowing some variety of implementation techniques.

Power. COMMON LISP is a descendant of MACLISP, which has always placed emphasis on providing system-building tools. Such tools may in turn be used to build the user-level packages such as INTERLISP provides; these packages are not, however, part of the COMMON LISP core specification. It is expected such packages will be built on top of the COMMON LISP core.

Expressiveness. COMMON LISP culls not only from MACLISP but also from INTERLISP, other LISP dialects, and other programming languages what we believe from experience to be the most useful and

understandable constructs. Constructs which have proved to be awkward or less useful have been eliminated (an example is the `store` construct of MACLISP).

Compatibility. Unless there is a good reason to the contrary, COMMON LISP strives to be compatible with Lisp Machine LISP, MACLISP, and INTERLISP, roughly in that order. Incompatibilities with various LISP dialects or other languages are noted here in the text in specially marked paragraphs.

Efficiency. COMMON LISP has a number of features designed to facilitate the production of high-quality compiled code in those implementations which care to invest effort in an optimizing compiler. At least one implementation of COMMON LISP will have such a compiler. This extends the work done in MACLISP to produce extremely efficient numerical code.

Stability. It is intended that COMMON LISP, once defined and agreed upon, will change only slowly and with due deliberation. The various dialects which are supersets of COMMON LISP may serve as laboratories within which to test language extensions, but such extensions will be added to COMMON LISP only after careful examination and experimentation.

The COMMON LISP documentation is divided into four parts, known for now as the blue pages, the white pages, the yellow pages, and the red pages. (This document is the white pages.)

- The *blue pages* constitute an implementation guide in the spirit of the INTERLISP Virtual Machine specification [1]. It specifies a subset of the white pages which an implementor must construct, and indicates a quantity of LISP code written in that subset which implements the remainder of the white pages. In principle there could be more than one set of blue pages, each with a companion file of LISP code. (For example, one might assume `if` to be primitive and define `cond` as a macro in terms of `if`, while another might do it the other way around.)

- The *white pages* (this document) is a language specification rather than an implementation specification. It defines a set of standard language concepts and constructs which may be used for communication of data structures and algorithms in the COMMON LISP dialect. This is sometimes referred to as the "core COMMON LISP language", because it contains conceptually necessary or important features. It is not necessarily implementationally minimal. While some features could be defined in terms of others by writing LISP code (and indeed may be implemented that way), it was felt that these features should be conceptually primitive so that there might be agreement among all users as to their usage. (For example, bignums and rational numbers could be implemented as LISP code given operations on fixnums. However, it is important to the conceptual integrity of the language that they be regarded by the user as primitive, and they are useful enough to warrant a standard definition.)

- The *yellow pages* is a program library document, containing documentation for assorted and relatively independent packages of code. While the white pages are to be relatively stable, the yellow pages are extensible; new programs of sufficient usefulness and quality will routinely be added from time to time. The primary advantage of the division into white and yellow pages is this relative stability; a package written solely in the white-pages language should not break if changes are made to the yellow-pages library.

- The *red pages* is implementation-dependent documentation; there will be one set for each

implementation. Here are specified such implementation-dependent parameters as word size, maximum array size, sizes of floating-point exponents and fractions, and so on, as well as implementation-dependent functions such as input/output primitives.

1.2. Notational Conventions

In COMMON LISP the empty list is written "`()`", which is not (necessarily) the same as the symbol named "`nil`". The empty list is, as in most LISP dialects, used to mean "false" in Boolean tests; therefore "false" is also written "`()`". Any non-`()` value is treated as being "true".

All numbers in this document are in decimal notation unless there is an explicit indication to the contrary.

Execution of code in LISP is called *evaluation*, because executing a piece of code normally results in a data object called the *value* produced by the code. The symbol "`=>`" will be used in examples to indicate evaluation. For example:

```
(+ 4 5) => 9
```

means "the result of evaluating the code `(+ 4 5)` is (or would be, or would have been) 9".

The symbol "`==>`" will be used in examples to indicate macro expansion. For example:

```
(push x v) ==> (setq v (cons x v))
```

means "the result of expanding the macro-call form `(push x v)` is `(setq v (cons x v))`". This implies that the two pieces of code do the same thing; the second piece of code is the definition of what the first does.

The symbol "`<=>`" will be used in examples to indicate code equivalence, For example:

```
(- x y) <=> (+ x (- y))
```

means "the value and effects of `(- x y)` is always the same as the value and effects of `(+ x (- y))` for any values of the variables `x` and `y`". This implies that the two pieces of code do the same thing; however, neither directly defines the other in the way macro-expansion does.

Functions, variables, special forms, and macros are described using a distinctive typographical format. Table 1-1 illustrates the manner in which COMMON LISP functions are documented. The first line specifies the name of the function, the manner in which it accepts arguments, and the fact that it is a function. Following indented paragraphs explain the definition and uses of the function and often present examples or related functions.

In general, the text of actual code (including actual names of functions) appears in this typeface: `(cons a b)`. Names which stand for pieces of code (meta-variables) are written in *italics*. In a function description, the names of the parameters appear in italics for expository purposes. The word "`&optional`" in the list of parameters indicates that all arguments past that point are optional; the default values for the parameters are described in the text. Parameter lists may also contain "`&rest`", indicating that an indefinite number of

`sample-function` *arg1 arg2* `&optional` *arg3 arg4* [*Function*]

The function `sample-function` adds together *arg1* and *arg2*, and then multiplies the result by *arg3*. If *arg3* is not provided or is `()`, the multiplication isn't done. `sample-function` then returns a list whose first element is this result and whose second element is *arg4* (which defaults to the symbol `foo`).

For example:

```
(function-name 3 4) => (7 foo)
(function-name 1 2 2 'bar) => (6 bar)
```

As a rule, `(sample-function x y) <=> (list (+ x y) 'foo)`.

Table 1-1: Sample Function Description

arguments may appear. (The `&optional` and `&rest` syntax is actually used in COMMON LISP function definitions for these purposes.)

`sample-variable` [*Variable*]

The variable `sample-variable` specifies how many times the special form `sample-special-form` should iterate. The value should always be a non-negative integer or `()` (which means iterate indefinitely many times). The initial value is `0`.

Table 1-2: Sample Variable Description

Table 1-2 illustrates the manner in which a global variable is documented. The first line specifies the name of the variable and the fact that it is a variable.

Tables SAMPLE-SPECIAL-FORM DESCRIPTION and 1-4 illustrate the documentation of special forms and macros (which are closely related in purpose). Functions are called according to a single,specific, consistent syntax; the `&optional` and `&rest` syntax specifies how the function uses its arguments internally, but does not affect the syntax of a call. In contrast, each special form or macro can have its own idiosyncratic syntax, for it is by special forms and macros that the syntax of COMMON LISP is defined and extended.

In the description of a special form or macro, an italicized word names a corresponding part of the form which invokes the special form or macro. Parentheses ("(" and ")") stand for themselves, and should be written as such when invoking the special form or macro. Square brackets ("[" and "]") indicate that what they enclose is optional (may appear zero times or one time in that place); the square brackets should not be

`sample-special-form` [*name*] ({*var*}*) {*form*}+ [*Special form*]

This evaluates each form in sequence as an implicit `progn`, and does this as many times as specified by the global variable `sample-variable`. Each variable *var* is bound and initialized to 43 before the first iteration, and unbound after the last iteration. The name *name*, if supplied, may be used in a `return-from` (page 58) form to exit from the loop prematurely. If the loop ends normally, `sample-special-form` returns `()`.

For example:

```
(setq sample-variable 3)
(sample-special-form () form1 form2)
```

This evaluates *form1*, *form2*, *form1*, *form2*, *form1*, *form2* in that order.

Table 1-3: Sample Special Form Description

`sample-macro` *var* {*tag* | *statement*}* [*Macro*]

This evaluates the statements as a `prog` body, with the variable *var* bound to 43.

```
(sample-macro x (+ x x)) => 86
(sample-macro var . body) ==> (prog ((var 43)) . body)
```

Table 1-4: Sample Macro Description

written in code. Curly braces ("{" and "}") simply parenthesize what they enclose, but may be followed by a star ("*") or a plus sign ("+"); a star indicates that what the braces enclose may appear any number of times (including zero, that is, not at all), while a plus sign indicates that what the braces enclose may appear any non-zero number of times (that is, must appear at least once). Within braces or brackets, vertical bars ("|") separate mutually exclusive choices.

In the last example in Table 1-4, notice the use of "dot notation". The "." in `(sample-macro` *var* . *body*) means that the name *body* stands for a list of forms, not just a single form, at the end of a list. This notation is often used in examples.

The term "LISP reader" refers not to you, the reader of this document, nor to some person reading LISP code, but specifically to a LISP program (the function `read` (page 197)) which reads characters from an input stream and interprets them by parsing as representations of LISP objects.

Certain characters are used in special ways in the syntax of COMMON LISP. The complete syntax is explained in detail in ???, but a quick summary here may be useful:

' An accent acute ("single quote") followed by an expression *form* is an abbreviation for `(quote form)`. Thus `'foo` means `(quote foo)` and `'(cons 'a 'b)` means `(quote (cons (quote a) (quote b)))`.

; Semicolon is the comment character. It and everything up to the end of the line is discarded.

" Double quotes surround character strings.

\ Backslash is an escape character. As a rule, it causes the next character to be treated as a letter rather than for its usual syntactic purpose. For example, `A\(B` denotes a symbol whose name is "A(B", and `"\""` denotes a character string containing one character, a double-quote.

The number sign begins a more complex syntax. The next character designates the precise syntax to follow. For example, `#o105` means 105– (105 in octal notation); `#\L` denotes a character object for the character "L"; and `#(a b c)` denotes a vector of three elements a, b, and c.

| Vertical bars surround the name of a symbol which has special characters in it.

` Accent grave ("backquote") signals that the next expression is a template which may contains commas. The backquote syntax represents a program which will construct a data structure according to the template.

, Commas are used within the backquote syntax.

: Colon is used to indicate which package a symbol belongs to. For example, `chaos:reset` denotes the symbol named `reset` in the package named `chaos`.

All code in this manual is written in lower case. COMMON LISP is generally insensitive to the case in which code is written. Every symbol has a print name which specifies how it is to be capitalized, but the symbol will be recognized even if entered in the wrong case. You may write programs in whichever case you prefer; COMMON LISP will attempt to preserve the capitalization you use. There are ways to force case conversion on input or output.

You will see various symbols that have the colon (:) character in their names. By convention, all "keyword" symbols have names starting with a colon. The colon character is not actually part of the print name, but is a package prefix indicating that the symbol belongs to the keyword package This is all explained in ???; until you read that, just make believe that the colons are part of the names of the symbols.

Chapter 2

Data Types

COMMON LISP provides a variety of types of data objects. It is important to note that in LISP it is data objects which are typed, not variables. Any variable can have any LISP object as its value.

In COMMON LISP, a data type is a (possibly infinite) set of LISP objects. Many LISP objects belong to more than one such set, and so it doesn't always make sense to ask what *the* type of an object is; instead, one usually asks only whether an object belongs to a given type. The predicate `typep` (page 28) may be used to ask either of these questions.

The data types defined in COMMON LISP are arranged into an almost-hierarchy (a hierarchy with shared subtrees) defined by the subset relationship. Certain sets of objects are interesting enough to deserve labels (such as the set of numbers or the set of strings). Symbols are used for most such labels (here, and throughout this document, the word *symbol* refers to atomic symbols, one kind of LISP object). The root of the hierarchy, which is the set of all objects, is labelled by `t`.

Objects may be roughly divided into the following categories (which are in fact types): `number`, `character`, `symbol`, `list`, `array`, `structure`, `function`, and `random`. Some of these categories have many subdivisions. There are also types which are the union of two or more of these categories. The categories listed above, while they are data types, are neither more nor less "real" than other data types; they simply constitute a particularly useful slice across the type hierarchy for expository purposes.

Each of these categories is described briefly below. Then one section of this chapter is devoted to each, going into more detail, and describing notations for objects of each type. Descriptions of LISP functions which operate on data objects are in later chapters.

- *Numbers* are provided in various forms and representations. COMMON LISP provides a true integer data type: any integer, positive or negative, has in principle a representation as a COMMON LISP data object, subject only to memory limitations (rather than machine word width). A true rational data type is provided: the quotient of two integers, if not an integer, is a ratio. Floating-point numbers of various ranges and precisions are also provided. Some implementations may choose to provide Cartesian complex numbers.

- *Characters* represent printed glyphs (such as letters) or text formatting operations. Strings are one-dimensional arrays of characters. COMMON LISP provides a rich character set, including ways

to represent characters of various type styles.

- *Symbols* (sometimes called *atomic symbols* for emphasis or clarity) are named data objects. LISP provides machinery for locating a symbol object, given its name (in the form of a string). Symbols have *property lists*, which in effect allow symbols to be treated as record structures with an extensible set of named components, each of which may be any LISP object.

- *Lists* are sequences represented in the form of linked cells called *conses*. There is a special object which is the empty list. All other lists are built recursively by adding a new element to the front of an existing list. This is done by creating a new *cons*, which is an object having two components called the *car* and the *cdr*. The *car* may hold anything, and the *cdr* is made to point to the previously existing list. (Conses may actually be used completely generally as two-element record structures, but their most important use is to represent lists.)

- *Arrays* are dimensioned collections of objects. An array can have any non-negative number of dimensions, and is indexed by a sequence of integers. General arrays can have any LISP object as a component; others are specialized for efficiency or for other reasons, and can hold only certain types of LISP objects. Two important special cases of arrays are *strings*, which are one-dimensional arrays of characters, and *bit-strings*, which are one-dimensional arrays that can contain only the integers 0 and 1.

- *Structures* are user-defined record structures, objects which have named components. The `defstruct` (page 167) facility is used to define new structure types. Some COMMON LISP implementations may choose to implement certain system-supplied data types as structures; these might include *bignums*, *readtables*, and *streams*.

- *Functions* are objects which can be invoked as procedures; these may take arguments, and return values. (All LISP procedures can be construed to return a value, and therefore treated as functions. Those which have nothing better to return usually return ( ).)

- *Random* objects are those which do not fit into any other category. This is a catch-all data type which primarily covers implementation-dependent objects for internal use.

2.1. Numbers

There are several kinds of numbers defined in COMMON LISP. Table 2-1 shows the hierarchy of number types.

2.1.1. Integers

The *integer* data type is intended to represent mathematical integers. Unlike most programming languages, COMMON LISP in principle imposes no limit on the magnitude of an integer; storage is automatically allocated as necessary to represent large integers.

In every COMMON LISP implementation there is a range of integers which are represented more efficiently than others; each such integer is called a *fixnum*, and an integer which is not a fixnum is called a *bignum*. The distinction between fixnums and bignums is visible to the user in only a few places where the efficiency of

```
number
    rational
        integer
            fixnum
            bignum
        ratio
    float
        short-float
        single-float
        double-float
        long-float
    complex
```

Table 2-1: Hierarchy of Numeric Types

representation is important; in particular, it is guaranteed that any dimension of an array (and therefore any index into an array) can be represented as a fixnum. Exactly which integers are fixnums is implementation-dependent; typically they will be those integers in the range -2^n to 2^n-1, inclusive, for some n not less than 15.

Implementation note: In the PERQ implementation of COMMON LISP, fixnums are those integers in the range $[-2^{27},2^{27}-1]$. In the S-1 implementation, fixnums are those integers in the range $[-2^{31},2^{31}-1]$. In the VAX implementation, fixnums are those integers in the range $[-2^{29},2^{29}-1]$.

flush

Integers are ordinarily written in decimal notation, as a sequence of decimal digits, optionally preceded by a sign and optionally followed by a decimal point.

For example:

```
                    0   ;Zero.
                   -0   ;This always means the same as 0.
                   +6   ;The first perfect number.
                   28   ;The second perfect number.
                 1024.  ;Two to the tenth power.
                   -1   ;e^(πi)
15511210043330985984000000.  ;25 factorial (25!). Probably a bignum.
```

Compatibility note: MACLISP and Lisp Machine LISP normally assume that integers are written in *octal* (radix-8) notation unless a decimal point is present. INTERLISP assumes integers are written in decimal notation, and uses a trailing Q to indicate octal radix; however, a decimal point, even in trailing position, *always* indicates a floating-point number. This is of course consistent with FORTRAN; ADA does not permit trailing decimal points, but instead requires them to be embedded. In COMMON LISP, integers written as described above are always construed to be in decimal notation, whether or not the decimal point is present; allowing the decimal point to be present permits compatibility with MACLISP.

There are special ways to notate integers in radices other than ten. The notation

#nnr ddddd

means the integer in radix-*nn* notation denoted by the digits *ddddd*. More precisely, one may write "#", a non-empty sequence of decimal digits representing an unsigned decimal integer *n*, "r" (or "R"), an optional sign, and a sequence of radix-*n* digits, to indicate an integer written in radix *n*. Only legal digits for the specified radix may be used; for example, an octal number may contain only the digits 0 through 7. Letters of

the alphabet of either case may be used in order for digits above 9. Binary, octal, and hexadecimal radices are useful enough to warrant the special abbreviations "#b" for "#2r", "#o" for "#8r", and "#x" for "#16r". For example:

```
#2r11010101   ; Another way of writing 213 decimal.
  #b11010101  ; Ditto.
 #b+11010101  ; Ditto.
     #o325    ; Ditto, in octal radix.
     #xD5     ; Ditto, in hexadecimal radix.
   #16r+D5    ; Ditto.
    #o-300    ; Decimal -192, written in base 8.
  #3r-12010   ; Same thing in base 3.
   #25R-7H    ; Same thing in base 25.
```

2.1.2. Floating-point Numbers

Generally speaking, a floating-point number is a (mathematical) rational number of the form $(-1)^{s}*f*2^{e-p}$, where s is a bit (0 or 1), the *sign*; p is a positive integer, the *precision* (in bits) of the floating-point number; f is a positive integer between 2^{p-1} and $2^{p}-1$ (inclusive), the *fraction* (properly speaking, the fraction is actually $f/2^{p}$); and e is an integer, the *exponent*. In addition, there is a floating-point zero. The value of p and the range of e depends on the implementation and on the type of floating-point number within that implementation.

Floating-point numbers are provided in a variety of precisions and sizes, depending on the implementation. High-quality floating-point software tends to depend critically on the precise nature of the floating-point arithmetic, and so may not always be completely portable. To aid in writing programs which are moderately portable, however, certain definitions are made here:

- A *short* floating-point number is the representation of smallest precision provided by an implementation.
- A *long* floating-point number is the representation of the largest fixed precision provided by an implementation.
- Intermediate between short and long sizes are two others, arbitrarily called *single* and *double*.

The precise definition of these categories is implementation-dependent. However, the rough intent is that short floating-point numbers be precise at least to about five decimal places; single floating-point numbers, at least to about seven decimal places; and double floating-point numbers, at least to about fourteen decimal places. Therefore the following minimum requirements are imposed on these formats: the precision (in bits) and the exponent size (in bits; that is, the base-2 logarithm of one plus the maximum exponent value) must be at least as great as the values in Table FLOATING-FORMAT-REQUIREMENTS-TABLE.

In any given implementation the categories may overlap or coincide. For example, short might mean the same as single, and long might mean the same as double.

> Implementation note: Where it is feasible, it is recommended that an implementation provide at least two types of floating-point number, and preferably three. Ideally, short-format floating-point numbers should have an "immediate"

Format	Minimum Precision	Minimum Exponent Size
Short	7 bits	20 bits
Single	8 bits	24 bits
Double	8 bits	50 bits

Table 2-2: Minimum Floating-Point Precision and Exponent Size Requirements

representation that does not require consing, single-format floating-point numbers should approximate IEEE standard single-format floating-point numbers, and double-format floating-point numbers should approximate IEEE standard double-format floating-point numbers.

In the PERQ SPICE LISP implementation of COMMON LISP, two types are to be provided:

- For the small size (28 bits), $p=20$ and e is in $[-128, 127]$. Short format maps to this.
- For the large size (96 bits), $p=63$ and e is in $[-2^{31}, 2^{31}-1]$. Single, double, and long formats map to this.

On the S-1, three types are provided:

- For halfword size (18 bits), $p=13$ and e is in $[-15, 16]$. Short format maps to this.
- For singleword size (36 bits), $p=27$ and e is in $[-255, 256]$. Single format maps to this.
- For doubleword size (72 bits), $p=57$ and e is in $[-2^{14}+1, 2^{14}]$. Double and long formats map to this.

The VAX architecture provides four floating-point formats:

- F-floating: 32 bits, $p=24$, e in $[-127, 127]$.
- D-floating: 64 bits, $p=56$, e in $[-127, 127]$.
- G-floating: 64 bits, $p=53$, e in $[-1023, 1023]$.
- H-floating: 128 bits, $p=113$, e in $[-16383, 16383]$.

Probably D-floating format should not be used. If so, then *short* and *single* might refer to F-floating format, *double* to G-floating format, and *long* to H-floating format (if that is supported; if not, then G-floating format). Alternatively, *short* format might be a 28-bit format consisting F-format with the four lowest-order fraction bits removed.

Floating point numbers are written in either decimal fraction or "computerized scientific" notation: an optional sign, then a non-empty sequence of digits with an embedded decimal point, then an optional decimal exponent specification. The decimal point is required, and there must be digits either before or after it; moreover, digits are required after the decimal point if there is no exponent specifier. The exponent specifier consists of an exponent marker, an optional sign, and a non-empty sequence of digits. For preciseness, here is an extended-BNF decription of floating-point notation. The notation "$\langle x \rangle^*$" means zero or more occurrences of "x", the notation "$\langle x \rangle^+$" means one or more occurrences of "x", and the notation "$\langle x \rangle^?$" means zero or one occurrences of "x".

⟨floating-point number⟩ ::= ⟨sign⟩$^?$ ⟨digit⟩* . ⟨digit⟩$^+$ ⟨exponent⟩$^?$ | ⟨sign⟩$^?$ ⟨digit⟩$^+$. ⟨digit⟩* ⟨exponent⟩
⟨sign⟩ ::= + | -
⟨digit⟩ ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
⟨exponent⟩ ::= ⟨exponent marker⟩ ⟨sign⟩$^?$ ⟨digit⟩$^+$
⟨exponent marker⟩ ::= e | s | f | d | l | E | F | D | S | L

If no exponent specifier is present, or if the exponent marker e (or E) is used, then the precise format to be used is not specified. When such a floating-point number representation is read and converted to an internal floating-point data object, the format specified by the variable `read-default-float-format` (page READ-DEFAULT-FLOAT-FORMAT-VAR) is used; the initial value of this variable is `single`.

The letters `s`, `f`, `d`, and `l` (or their respective upper-case equivalents) specify explicitly the use of *short*, *single*, *double*, and *long* format, respectively.

??? Query: There has been some objection to the use of the words *single* and *double*, as they may be misleading to the user or too confining for the implementor. Any suggestions?

For example:

```
0.0                              ; Floating-point zero in default format.
-.0                              ; Also a floating-point zero.
0.                               ; The integer zero, not a floating-point number!
0.0s0                            ; A floating-point zero in short format.
3.14159265358979323 84d0         ; A double-format approximation to π.
3.14159265358979323 84B0         ; A big-format approximation to π.
6.02E+23                         ; Avogadro's number, in default format.
3.1010299957f-1                  ; log10 2, in single format.
-0.000000001s9                   ; e^π in short format, the hard way.
```

2.1.3. Ratios

The rationals include the integers, and also *ratios* of two integers. The canonical printed representation of a rational number is as an integer if its value is integral, and otherwise as the ratio of two integers, the *numerator* and *denominator*, whose greatest common divisor is one, and of which the denominator is positive (and in fact greater than 1, or else the value would be integral), written with "`/`" as a separator thus: "`3/5`". It is possible to notate ratios in non-canonical (unreduced) forms, such as "`4/6`", but the LISP function `print` (page 201) always prints the canonical form for a ratio.

Implementation note: While ~~each~~ implementation of COMMON LISP will probably choose to maintain all ratios in reduced form, there is no requirement for this as long as its effects are not visible to the user. Note that while it may at first glance appear to save computation for the reader and various arithmetic operations not to have to produce reduced forms, this savings is likely to be counteracted by the increased cost of operating on larger numerators and denominators.

Rational numbers may be written as the possibly signed quotient of decimal numerals: an optional sign followed by two non-empty sequences of digits separated by a "`/`". The second sequence may not consist entirely of zeros.

For example:

```
2/3                              ; This is in canonical form.
4/6                              ; A non-canonical form for the same number.
-17/23
-30517578125/32768               ; This is (-5/2)^15.
10/5                             ; The canonical form for this is 2.
```

There are ways to notate rational numbers in radices other than ten; one uses the same radix specifiers (one of `#`*nn*`R`, `#O`, `#B`, or `#X`) as for integers.

For example:

```
#o-101/75                        ; Octal notation for -65/61.
#3r120/21                        ; Ternary notation for 15/7.
#Xbc/ad                          ; Hexadecimal notation for 188/173.
```

Tie this to a FEATURE ?

2.1.4. Complex Numbers

Complex numbers may or may not be supported by a COMMON LISP implementation. They are represented in Cartesian form, with a real part and an imaginary part each of which is a non-complex number (integer, floating-point number, or ratio). It should be emphasized that the parts of a complex number are not necessarily floating-point numbers; in this COMMON LISP is like PL/I and differs from FORTRAN. In general, these identities hold:

```
(eql (realpart (complex x y)) x)
(eql (imagpart (complex x y)) y)
```

Complex numbers may be notated by writing the characters "#C" followed by a list of the real and imaginary parts. (Indeed, "`#C(a b)`" is equivalent to "`#,(complex a b)`"; see the description of the function `complex` (page 130).)

Query J notation.

For example:

```
#C(3.0s1 2.0s-1)
#C(5 -3)                    ;A Gaussian integer.
#C(5/3 7.0)
```

Some implementations furthermore provide specialized representations of complex numbers for efficiency. In such representations the real part and imaginary part are of the same specialized numeric type. The "#C" construct will produce the most specialized representation which will correctly represent the two notated parts. The type of a specialized complex number is indicated by a list of the word `complex` and the type of the components; for example, a specialized representation for complex numbers with short floating-point parts would be of type `(complex short-float)`. The type `complex` encompasses all complex representations; the particular representation which allows parts of any numeric type is referred to as type `(complex t)`.

Quick! Flash Font.

2.2. Characters

Every character object has three attributes: *code*, *bits*, and *font*. The code attribute is intended to distinguish among the printed glyphs and formatting functions for characters. The bits attribute allows extra flags to be associated with a character. The font attribute permits a specification of the style of the glyphs (such as italics). Each of these attributes may be understood to be a non-negative integer.

A character object can be notated by writing "#\" followed by the character itself. For example, "`#\g`" means the character object for a lower-case "g". This works well enough for "printing characters". Non-printing characters have names, and can be notated by writing "#\" and then the name; for example, "`#\return`" (or "`#\RETURN`" or "`#\Return`", for example) means the <return> character. The syntax for character names after "#\" is the same as that for symbols.

The font attribute may be notated in unsigned decimal notation between the "#" and the "\". For example, `#3\A` means the letter "A" in font 3. Note that not all COMMON LISP implementations provide for non-zero font attributes; see `char-font-limit` (page 139).

The bits attribute may be notated by preceding the name of the character by the names or initials of the bits, separated by hyphens. The character itself may be written instead of the name, preceded if necessary by "\". For example:

```
#\Control-Meta-Return
#\Hyper-Space
#\Control-A
#\Meta-\β
#\C-M-Return
```

Note that not all COMMON LISP implementations provide for non-zero bits attributes; see `char-font-limit` (page 139).

Any character whose bits and font attributes are zero may be contained in strings. All such characters together constitute a subtype of the characters; this subtype is called `string-char`.

2.3. Symbols

Symbols are LISP data objects which serve several purposes and several interesting properties. Every symbol has a name, called its *print name*, or *pname*. Given a symbol, one can obtain its name in the form of a string. More interesting, given the name of a symbol as a string one can obtain the symbol itself. (More precisely, symbols are organized into *packages*, and all the symbols in a package are uniquely identified by name.)

Symbols have a component called the *property list*, or *plist*. By convention this is always a list whose even-numbered components (calling the initial one component zero) are symbols, here functioning as property names, and whose odd-numbered components are associated property values. Functions are provided for manipulating this property list; in effect, these allow a symbol to be treated as an extensible record structure.

Symbols are also used to represent certain kinds of variables in LISP programs, and there are functions for dealing with the values associated with symbols in this role.

A symbol can be notated simply by writing its name. If its name is not empty, and if the name consists only of upper-case alphabetic, numeric, or certain "pseudo-alphabetic" special characters (but not delimiter characters such as parentheses or space), and if the name of the symbol cannot be mistaken for a number, then the symbol can be notated by the sequence of characters in its name.

For example:

```
FROBBOZ                 ;The symbol whose name is "FROBBOZ".
frobboz                 ;Another way to notate the same symbol.
fRObBoz                 ;Yet another way to notate it.
unwind-protect          ;A symbol with a "-" in its name.
+$                      ;The symbol named "+$".
1+                      ;The symbol named "1+".
+1                      ;This is the integer 1, not a symbol.
pascal_style            ; This symbol has an underscore in its name.
b^2-4*a*c               ;This is a single symbol!
                        ;    It has several special characters in its name.
file.rel.43             ;This symbol has periods in its name.
/usr/games/zork         ;This symbol has slashes in its name.
```

Besides letters and numbers, the following characters are normally considered to be "alphabetic" for the purposes of notating symbols:

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

Some of these characters have conventional purposes for naming things; for example, symbols which name functions having extremely implementation-dependent semantics generally have names beginning with "%". The last character, ".", is considered alphabetic *provided* that it does not stand alone. By itself, it has a role in the notation of conses. (It also serves as the decimal point.)

A symbol may have upper-case letters, lower-case letters, or both in its print name. However, the LISP reader normally converts lower-case letters to the corresponding upper-case letters when reading symbols. The net effect is that most of the time case makes no difference when *notating* symbols. However, case *does* make a difference internally and when printing a symbol. Internally the symbols which name all standard COMMON LISP functions, variables, and keywords have upper-case names; their names appear in lower case in this document for readability. Typing such names in lower case works because the function `read` will convert them to upper case.

If a symbol cannot be notated simply by the characters of its name, because the (internal) name contains special characters or lower-case letters, then there are two "escape" conventions for notating them. Writing a "\" character before any character causes the character to be treated itself as an ordinary character for use in a symbol name. If any character in a notation is preceded by \, then that notation can never be interpreted as a number.

For example:

```
\(                      ;The symbol whose name is "(".
\+1                     ;The symbol whose name is "+1".
+\1                     ;Also the symbol whose name is "+1".
\frobboz                ;The symbol whose name is "fROBBOZ".
3.14159265\s0           ;The symbol whose name is "3.14159265s0".
3.14159265\S0           ;The symbol whose name is "3.14159265S0".
3.14159265s0            ;A short-format floating-point approximation to π.
APL\\360                ;The symbol whose name is "APL\360".
\(b^2\)\ -\ 4*a*c       ;The name is "(b^2) - 4*a*c".
                        ;    It has parentheses and two spaces in it.
```

It may be tedious to insert a "\" before *every* delimiter character in the name of a symbol if there are many

of them. An alternative convention is to surround the name of a symbol with vertical bars; these cause every character between them to be taken as part of the symbol's name, as if "\" had been written before each one, excepting only | itself and \, which must nevertheless be preceded by \.

For example:

```
|"|                    ;The same as writing \".
|(b^2) - 4*a*c|        ;The name is "(b^2) - 4*a*c".
|frobboz|              ;The name is "frobboz", not "FROBBOZ".
|APL\360|              ;The name is "APL360", because
                       ;    the "\" quotes the "3".
|APL\\360|             ;The name is "APL\360".
|apl\\360|             ;The name is "apl\360".
|\|\||                ;Same as \|\|: the name is "||".
```

2.4. Lists and Conses

A *cons* is a little record structure containing two components, called the *car* and the *cdr*. Conses are used primarily to represent lists.

A *list* is recursively defined to be either the empty list, which is a special data object notated as "()", or a cons whose *cdr* component is a list. A list is therefore a chain of conses linked by their *cdr* components and terminated by (). The *car* components of the conses are called the *elements* of the list. For each element of the list there is a cons. The empty list has no elements at all.

A list is notated by writing the elements of the list in order, separated by blank space (space, tab, or return characters) and surrounded by parentheses.

For example:

```
(a b c)                ;A list of three symbols.
(2.0s0 (a 1) #\*)      ;A list of three things: a short floating-point number,
                       ;    another list, and a character object.
```

This is why the empty list is written as (); it is a list with no elements.

A *dotted list* is one whose last cons does not have () for its *cdr*, but some other data object (which is also not a cons, or the first-mentioned cons would not be the last cons of the list). Such a list is called "dotted" because of the special notation used for it: the elements of the list are written between parentheses as before, but after the last element and before the right parenthesis are written a dot (surrounded by blank space) and then the *cdr* of the last cons. As a special case, a single cons is notated by writing the car and the cdr between parentheses and separated by a space-surrounded dot.

For example:

```
(a . 4)                ;A cons whose car is a symbol
                       ;    and whose cdr is an integer.
(a b c . d)            ;A list with three elements whose last cons
                       ;    has the symbol d in its cdr.
```

Compatibility note: In MACLISP, the dot in dotted-list notation needed not be surrounded by white space or other delimiters.

The dot is required to be delimited in Lisp Machine LISP.

It is legitimate to write something like `(a b . (c d))`; this means the same as `(a b c d)`. The standard LISP output routines will never print a list in the first form, however; they will avoid dot notation wherever possible.

Often the term *list* is used to refer either to true lists or to dotted lists. The term "true list" will be used to refer to a list terminated by `()`, when the distinction is important. Most functions advertised to operate on lists ~~will work on dotted lists and ignore the non-`()` *cdr* at the end.~~ nominally require dotted lists.

Sometimes the term *tree* is used to refer to some cons and all the other conses transitively accessible to it through *car* and *cdr* links until non-conses are reached; these non-conses are called the *leaves* of the tree. Non-conses are also considered to be (trivial) trees.

Lists, dotted lists, and trees are not mutually exclusive data types; they are simply useful points of view about structures of conses. There are yet other terms, such as *association list*. None of these are true LISP data types. Conses are a data type, and `()` is the sole object of type `null`. The LISP data type `list` is taken to mean the union of the `cons` and `null` data types, and therefore encompasses both true lists and dotted lists.

clisp

Vectors

clisp

2.5. Arrays

An *array* is an object with components arranged according to a rectilinear coordinate system. In general, these components may be any LISP data objects.

The number of dimensions of an array is called its *rank* (this terminology is borrowed from APL). This is a non-negative integer; for convenience, it is in fact required to be a fixnum (an integer of limited magnitude). Likewise, each dimension has a length which is a non-negative fixnum. The total number of elements in the array is the product of all the dimensions.

Query: impls limit rank?

It is permissible for a dimension to be zero. In this case, the array has no elements, and any attempt to access an element in in error. However, other properties of the array (such as the dimensions themselves) may be used. If the rank is zero, then there are no dimensions, and the product of the dimensions is then by definition 1. A zero-rank array therefore has a single element.

e

An array element is specified by a sequence of indices. The length of the sequence must equal the rank of the array. Each index must be a non-negative integer strictly less than the corresponding array dimension. Array indexing is therefore zero-origin, not one-origin as in (the default case of) FORTRAN.

ref

As an example, suppose that the variable `foo` names a 3-by-5 array. Then the first index may be 0, 1, or 2, and then second index may be 0, 1, 2, 3, or 4. One may refer to array elements using the function `aref` (page 160):

```
(aref foo 2 1)
```

refers to element (2,1) of the array. Note that `aref` takes a variable number of arguments: an array, and as many indices as the array has dimensions. A zero-rank array has no dimensions, and therefore `aref` would

take such an array and no indices, and return the sole element of the array.

One-dimensional arrays and lists are collectively considered to be *sequences*. They differ in that any component of a one-dimensional array can be accessed in constant time, while the average component access time for a list is linear in the length of the list; on the other hand, adding a new element to the front of a list takes constant time, while the same operation on an array takes time linear in the length of the array.

In general, arrays can be multi-dimensional, can have *fill pointers*, can share their contents with other array objects, and can have their size altered dynamically after creation. The important special case of a one-dimensional array with no fill pointer, unshared with any other array, and of unincreasable size is called a *vector*. Some implementations can handle vectors in an especially efficient manner.

The general notation for arrays is rather complicated. It generally begins with "#*n*A", where *n* is the rank of the array, and is followed by a description of the contents of the array. The notation is described in full in ???.

A general vector (a one-dimensional array of S-expressions with no additional paraphernalia) can be notated by notating the components in order, separated by whitespace and surrounded by "#(" and ")".

For example:

```
#(a b c)                        ;A vector of length 3.
#(2 3 5 7 11 13 17 19 23 29 31 37 41 43 47)
                                ;A vector containing the primes below 50.
#()                             ;An empty vector.
```

Rationale: Numerous people have suggested that square brackets be used to notate vectors ("`[a b c]`" instead of "`#(a b c)`"). This would be shorter, perhaps more readable, and certainly in accord with cultural conventions in other parts of computer science and mathematics. However, to preserve the usefulness of the user-definable macro-character feature of the function `read` (page 197), it is necessary to leave some characters to the user for this purpose. Experience in MACLISP has shown that users, especially implementors of AI languages, often want to define special kinds of brackets. Therefore COMMON LISP avoids using these characters in its syntax so that the user may freely redefine their syntax: "`[]{}!?`".

Implementations may provide certain specialized representations of arrays for efficiency in the case where all the components are of the same specialized (typically numeric) type. All implementations provide specialized arrays for the cases when the components are characters or when the components are always 0 or 1; the one-dimensional instances of these specializations are respectively called *strings* and *bit-strings*. Special notations are provided for the further restriction of these types to the vector case. A string vector can be written as the sequence of characters contained in the string, preceded and followed by a "`"`" (double-quote) character. Any "`"`" or "`\`" character in the sequence must additionally have a "`\`" character before it.

For example:

```
"Foo"                           ;A string with three characters in it.
""                              ;An empty string.
"\"APL\\360?\" he cried."       ;A string with twenty characters.
"|x| = |-x|"                    ;A ten-character string.
```

Notice that any vertical bar "`|`" in a string need not be preceded by a "`\`". Similarly, any double-quote in the name of a symbol written using vertical-bar notation need not be preceded by a "`\`". The double-quote and vertical-bar notations are similar but distinct: double-quotes indicate a character string containing the

sequence of characters, while vertical bars indicate a symbol whose name is the contained sequence of characters.

A bit-string vector is written much like a string, using double-quotes; however, a "#" is written before it, and the elements of the bit vector must be 0 or 1.

For example:

```
#"10110"                    ;A bit vector with five bits. Bit 0 is 1.
#""                         ;A null bit vector.
#"110101000101000101"       ;Bit n of this bit vector is 1 iff n+2 is prime.
```

2.6. Structures

Different structures may print out in different ways; the definition of a structure type may specify a print procedure to use for objects of that type (see the `:printer` (page DEFSTRUCT-PRINTER-KWD) option to `defstruct` (page 167)). The default notation for structures is:

```
#S( structure-name
          slot-name-1  slot-value-1
          slot-name-2  slot-value-2
                              ...)
```

where "#S" indicates structure syntax, *structure-name* is the name (a symbol) of the structure type, each *slot-name* is the name (also a symbol) of a component, and each corresponding *slot-value* is the representation of the LISP object in that slot.

2.7. Functions

2.8. Randoms

Objects of type `random` tend to have implementation-dependent semantics, and so may print in implementation-dependent ways. As a rule, such objects cannot reliably be reconstructed from a printed representation, and so they are printed usually in a format informative to the user but not acceptable to the `read` function:

#<useful information>

A hypothetical example might be:

```
#<stack-pointer si:rename-within-new-definition-maybe 311037552>
```

The LISP reader will signal an error on encountering "#<".

It is not necessarily the case that all objects which are printed in the form "#<...>" are of type `random`; however, any object of type `random` will be printed in that form.

Chapter 3

Program Structure

In the previous chapter the syntax was sketched for notating data objects in COMMON LISP. The same syntax is used for notating programs, because all COMMON LISP programs have a representation as COMMON LISP data objects.

3.1. Forms

The standard unit of interaction with a COMMON LISP implementation is the *form*, which is simply an S-expression meant to be *evaluated* as a program to produce ~~one or more~~ *values* (which are also data objects). One may request evaluation of *any* data object, but only certain ones (such as symbols and lists) are meaningful forms, while others (such as most arrays) are not. Examples of meaningful forms are 3, whose value is 3, and `(+ 3 4)`, whose value is 7. We write "`3 => 3`" and "`(+ 3 4) => 7`" to indicate these facts ("`=>`" means "evaluates to").

Meaningful forms may be divided into three categories: self-evaluating forms, such as numbers; symbols, which stand for variables; and lists. The lists in turn may be divided into three categories: special forms, macro calls, and function calls.

3.1.1. Self-Evaluating Forms

All numbers, strings, and bit-strings are *self-evaluating* forms. When such an object is evaluated form, that object itself (or possibly a copy in the case of numbers) is returned as the value of the form. The empty list `()` is also a self-evaluating form: the value of `()` is `()`.

3.1.2. Variables

Symbols are used as names of variables in COMMON LISP programs. When a symbol is evaluated as a form, the value of the variable it names is produced. For example, after doing `(setq items 3)`, which assigns the value 3 to the variable named `items`, then `items => 3`. Variables can be *assigned* to (as by `setq` (page 39)) or *bound*. Any program construct that binds a variable effectively saves the old value of the variable and causes it to have a new value, and on exit from the construct the old value is reinstated.

There are actually two kinds of variables in COMMON LISP, called *lexical* (or *static*) variables and *special* (or

dynamic) variables. At any given time either or both kinds of variable with the same name may have a current value. Which of the two kinds of variable is referred to when a symbol is evaluated depends on the context of the evaluation. The general rule is that if the symbol occurs textually within a program construct that creates a *binding* for a variable of the same name, then the reference is to the kind of variable specified by the binding; if no such program construct textually contains the reference, then it is taken to refer to the special variable of that name.

The distinction between the two kinds of variable is one of scope and access. A lexically bound variable can be referred to *only* by forms occurring at any *place* textually within the program construct that binds the variable. A dynamically bound (special) variable can be referred to at any *time* from the time the binding is made until the time evaluation of the construct that binds the variable terminates. Therefore lexical binding imposes spatial limitations on occurrences of references, whereas dynamic binding imposes temporal limitations.

The value a special variable has when there are currently no bindings of that variable is called the *global* value of the variable. A global value can be given to a variable only by assignment, because a value given by binding by definition is not global.

The symbols `t` and `nil` are reserved. One may not assign a value to `t` or `nil`, and one may not bind `t` or `nil`. The global value of `t` is always ~~a *true* (non-( )) value~~, and the global value of `nil` is always *false* (( )). Constant symbols defined by `defconst` (page 23) also become reserved and may not be further assigned to or bound.

> Rationale: It would seem appropriate for the compiler to be justified in issuing a warning if one does a `setq` on a constant defined by `defconst`. If one cannot assign, one should not be able to bind, either.
>
> ??? Query: Unfortunately this violates the principle of alpha-conversion for lexical variables. What would people think of forbidding only *special* bindings of `t` and `nil`, but permitting lexical bindings (and *caveat* the hacker who writes
>
> ```
> (defun time-dependent-fn (t)
>   (cond ((plusp t) 5) (t -5)))
> ```
>
> or something similar. Actually, that particular one would probably work anyway...)? This allows someone using lexical variables to use any name without interference from the rest of the world, and also prevents anyone from clobbering global variables such as `t` on the constancy of which other functions depend.

3.1.3. Special Forms

If a list is to be evaluated as a form, the first step is to examine the first element of the list. If the first element is one of the symbols appearing in Table SPECIAL-FORM-TABLE, then the list is called a *special form*. (This use of the word "special" is unrelated to its use in the phrase "special variable".)

(The page numbers indicate where the definitions of these special forms appear.)

Table 3-1: Names of All COMMON LISP Special Forms

Special forms are generally environment and control constructs. Every special form has its own idiosyncratic syntax. An example is the `if` special form: "`(if p (+ x 4) 5)`" in COMMON LISP means what "if p then $x+4$ else 5" would mean in ALGOL.

The evaluation of a special form normally produces a value (but it may instead call for a non-local exit (see `throw` (page 65)) or produce no values or more than one value (see `values` (page 59))).

The set of special forms is fixed in COMMON LISP; no way is provided for the user to define more. The user can create new syntactic constructs, however, by defining macros.

3.1.4. Macros

If a form is a list and the first element is not the name of a special form, it may be the name of a *macro*; if so, the form is said to be a *macro call*. A macro is essentially a function from forms to forms that will, given a call to that macro, compute a new form to be evaluated in place of the macro call. (This computation is sometimes referred to as *macro expansion*.) For example, the macro named `push` (page 92) will take a form such as `(push x stack)` and from that form compute a new form `(setf stack (cons x stack))`. We say that the old form *expands* into the new form. The new form is then evaluated in place of the original form; the value of the new form is returned as the value of the original form.

There are a number of standard macros in COMMON LISP, and the user can define more by using `defmacro` (page DEFMACRO-FUN).

3.1.5. Function Calls

If a list is to be evaluated as a form and the first element is not a symbol that names a special form or macro, then the list is assumed to be a *function call*. The first element of the list is taken to name a function. Any and all remaining elements of the list are forms to be evaluated; one value is obtained from each form, and these values become the *arguments* to the function. The function is then *applied* to the arguments. The functional computation normally produces a value (but it may instead call for a non-local exit (see `throw` (page 65)) or produce no values or more than one value (see `values` (page 59))). If and when the function returns, whatever value(s) it returns ~~becomes~~ will become the value(s) of the function-call form.

For example, consider the evaluation of the form `(+ 3 (* 4 5))`. The symbol + names the addition function, not a special form or macro. Therefore the two forms 3 and `(* 4 5)` are evaluated to produce arguments. The form 3 evaluates to 3, and the form `(* 4 5)` is a function call (to the multiplication function). Therefore the forms 4 and 5 are evaluated, producing arguments 4 and 5 for the multiplication. The multiplication function calculates the number 20 and returns it. The values 3 and 20 are then given as arguments to the addition function, which calculates and returns the number 23. Therefore we say `(+ 3 (* 4 5)) => 23`.

3.2. Functions

There are two ways to indicate a function to be used in a function call form. One is to use a symbol that names the function. This use of symbols to name functions is completely independent of their use in naming special and lexical variables. The other way is to use a *lambda-expression*, which is a list whose first element is the symbol `lambda`. A *lambda-expression* is *not* a form; it cannot be meaningfully evaluated. Lambda-expressions and symbols as names of functions can appear only as the first element of a function-call form, or as the second element of the `function` (page 38) special form.

3.2.1. Named Functions

A name can be given to a function in one of two ways. A *global name* can be given to a function by using the `defun` (page DEFUN-FUN) special form. A *local name* can be given to a function by using the `labels` (page LABELS-FUN) special form. If a symbol appears as the first element of a function-call form, then it refers to the definition established by the innermost `labels` construct that textually contains the reference, or if to the global definition (if any) if there is no such containing `labels` construct.

When a function is named, a lambda-expression is associated with that name (in effect). See `defun` (page DEFUN-FUN) and `labels` (page LABELS-FUN) for an explanation of these lambda-expressions.

3.2.2. Lambda-Expressions

A *lambda-expression* is a list with the following syntax:

(`lambda` *lambda-list* . *body*)

The first element must be the symbol `lambda`. The second element must be a list. It is called the *lambda-list*, and specifies names for the *parameters* of the function. When the function denoted by the lambda-expression is applied to arguments, the arguments are matched with the parameters specified by the lambda-list. The *body* may then refer to the arguments by using the parameter names. The *body* consists of any number of forms (possibly zero). These forms are evaluated in sequence, and the value(s) of the *last* form only are returned as the value(s) of the application (the empty list ( ) is returned if there are zero forms in the body).

The complete syntax of a lambda-expression is:

```
(lambda ({var}*
        {[&optional {var | (var [initform [svar]])}*] [&rest var]
         | [&key {var | ((keyword var)}*
                 [&optional {var | (var | (keyword var)} [initform [svar]])}*]]}
        [&aux {var | (var [initform])}*])
  {form}*)
```

Each element of a lambda-list is either a *parameter specifier* or a *separator token*; separator tokens begin with "&". In all cases *var* must be a symbol, the name of a variable, and similarly for *svar*; *keyword* must be a keyword symbol. An *initform* may be any form.

A lambda-list has three parts, any or all of which may be empty:

- Specifiers for the *required* parameters. These are all the parameter specifiers up to the first separator token; if there is no such token, then all the specifiers are for required parameters.

- Either *optional* and *rest* parameters or *keyword* parameters (but not both).

  - If the token `&key` is not present, then the *optional* parameter specifiers are those following the token `&optional` up to the next separator token or the end of the list. Following the optional parameter specifiers may be a single *rest* parameter specifier preceded by the token `&rest`.

  - If the token `&key` is present, all specifiers up to the `&aux` token or the end of the list are *keyword* parameter specifiers. Any appearing after the token `&optional` are *optional keyword* parameters; all others are *required keyword* parameters.

- If the token `&aux` is present, all specifiers after it are *auxiliary variable* specifiers.

Sometimes *required* and *optional* parameters are called *required positional* parameters and *optional positional* parameters to contrast them explicitly with required and optional keyword parameters.

Compatibility note: What is provided here is a subset of the functionality currently provided in Lisp Machine LISP. The principal restrictions here are:

- Keyword parameters may not be mixed with positional optional and rest parameters. The rationale for not mixing keyword parameters and positional optionals is that it would be very awkward to define a function in such a way that one could not specify any keyword parameters unless all positional optionals were specified. If the positional ones are to be non-trivially optional, then all the keyword parameters should also be optional, and as a matter of style it would be better for all the optional parameters to have keywords. (We know how to make interleaved required and optional positional parameters work, too, but as a matter of style we only allow optionals to follow required.) The rationale for not mixing keyword and rest parameters is less strong, and motivated primarily by a feeling of awkwardness in letting more than one parameter receive the same argument. If we allow that, then why not `(&rest x a b &optional c d)`?

- No keyword argument may be provided for which there is no matching keyword parameter. This is a logical consequence of not mixing keyword and rest parameters, and also greatly improves program readability: the lambda-list enumerates all relevant keywords. Is non-trivial use made of `&allow-extra-keywords` in Lisp Machine LISP?

- The user may specify that some keyword arguments are required while other are optional, instead of all of them being optional. The implementor is encouraged to error-check, of course.

How do people feel about this? Lisp Machine LISP will run correct programs constructed according to the above specifications (modulo accepting `&optional` after `&key`), but may want to error-check required keyword arguments.

When the function represented by the lambda-expression is applied to arguments, the arguments and parameters are processed in order from left to right. In the simplest case, only required parameters are present in the lambda-list; each is specified simply by a name *var* for the parameter variable. When the function is applied, there must be exactly as many arguments as there are parameters, and each parameter is bound to one argument. Here, and in general, the parameter is bound as a lexical variable unless a declaration has been made that it should be a special binding (see `declare` (page 72)).

In the more general case, if there are n required parameters (n may be zero), there must be at least n arguments, and the required parameters are bound to the first n arguments. The other parameters are then processed using any remaining arguments.

If *optional* parameters are specified, then each one is processed as follows. If any unprocessed arguments remain, then the parameter variable *var* is bound to the next remaining argument, just as for a required parameter. If no arguments remain, however, the *initform* part of the parameter specifier is evaluated, and the parameter variable is bound to the resulting value (or to ( ) if no *initform* appears in the parameter specifier). If another variable name *svar* appears in the specifier, it is bound to *true* if an argument was available, and to *false* if no argument remained (and therefore *initform* had to be evaluated). The variable *svar* is called a *supplied-p* parameter; it is not bound to an argument, but to a value indicating whether or not an argument had been supplied for another parameter.

After all *optional* parameter specifiers have been processed, then there may or may not be a *rest* parameter. If there is none, then there should be no unprocessed arguments (it is an error if there are). If there is a *rest* parameter, it is bound to a list of all as-yet-unprocessed arguments. (If no unprocessed arguments remain, the *rest* parameter is bound to ( ).)

Instead of *optional* and *rest* parameters, *keyword* parameters may be specified instead. In that case, after all required parameters (and an equal number of arguments) have been processed, there must remain an even number of arguments; these are processed in pairs, the first argument in each pair being interpreted as a keyword name and the second as the corresponding value. No two argument pairs should have the same keyword name.

In each keyword parameter specifier must be a name *var* for the parameter variable. If an explicit *keyword* is specified, that is the keyword name for the parameter; otherwise the name *var* serves also as the keyword name. For each keyword parameter specifier, if there is an argument pair whose keyword name matches that specifier's keyword name, then the parameter variable for that specifier is bound to the second item (the value) of that argument pair. If no such argument pair exists, then it is an error unless the keyword parameter specifier occurs after the `&optional` token, in which case the *initform* for that specifier is evaluated and the parameter variable is bound to that value (or to ( ) if no *initform* was specified). The variable *svar* is treated as for ordinary *optional* parameters: it is bound to *true* if there was a matching argument pair, and to *false* otherwise. It is an error if an argument pair has a keyword name not matched by any parameter specifier.

After all parameter specifiers have been processed, the auxiliary variable specifiers (those following the token `&aux`) are processed from left to right. For each one the *initform* is evaluated and the variable *var* bound to that value (or to ( ) if no *initform* was specified). (Nothing can be done with `&aux` variables that cannot be done with the special form `let` (page 43). Which to use is purely a matter of style.)

As a rule, whenever any *initform* is evaluated for any parameter specifier, that form may refer to any parameter variable to the left of the specifier in which the *initform* appears, including any supplied-p variables, and may rely on no other parameter variable having yet been bound (including its own parameter variable).

> Compatibility note: At present, one cannot depend on this in Lisp Machine Lisp for keyword parameters. It is the "obvious" generalization of the current state of affairs for optional parameters and aux variables. Opinions?

Once the lambda-list has been processed, the forms in the body of the lambda-expression are executed.

These forms may refer to the arguments to the function by using the names of the parameters. On exit from the function, either by a normal return of the function's value(s) or by a non-local exit, the parameter bindings (whether lexical or special) are no longer in effect; any such binding can later be reinstated only if a *closure* over that binding was created and saved before the exit occurred.

Examples:

```
((lambda (a b) (+ a (* b 3))) 4 5) => 19
((lambda (a &optional (b 2)) (+ a (* b 3))) 4 5) => 19
((lambda (a &optional (b 2)) (+ a (* b 3))) 4) => 10
((lambda (&optional (a 2 b) (c 3 d) &rest x) (list a b c d x)))
   => (2 () 3 () ())
((lambda (&optional (a 2) (c 3) &rest x) (list a c x)) 6)
   => (6 t 3 () ())
((lambda (&optional (a 2) (c 3) &rest x) (list a c x)) 6 3)
   => (6 t 3 t ())
((lambda (&optional (a 2) (c 3) &rest x) (list a c x)) 6 3 8)
   => (6 t 3 t (8))
((lambda (&optional (a 2) (c 3) &rest x) (list a c x)) 6 3 8 9 10 11)
   => (6 t 3 t (8 9 10 11))
```

The `&optional`, `&rest`, and `&key` parameter specifiers are not terribly useful in lambda-expressions appearing explicitly as the first element of a function-call form. They are extremely useful, however, in functions given global names by `defun`.

3.3. Top-Level Forms

The standard way for the user to interact with a COMMON LISP implementation is via what is called a *read-eval-print loop*: the system repeatedly reads a form from some input source (such as a keyboard or a disk file), evaluates it, and then prints the value(s) to some output sink (such as a display screen or another disk file). As a rule any form (evaluable S-expression) is acceptable. However, certain special forms are specifically designed to be convenient for use as *top-level* forms, as opposed to forms embedded within other forms; as `(+ 2 7)` is embedded within `(if p (+ 2 7) 9)`. These top-level special forms may be used to define globally named functions, to define macros, to make declarations, and to define global values for special variables.

Which can be used at other than top level?

3.3.1. Defining Named Functions

`defun` *name lambda-list* {`(declare` {*declaration*}`)`}* [*doc-string*] {*form*}* [*Special form*]

Evaluating this special form causes the symbol *name* to be a global name for the function specified by the lambda-expression

`(lambda` *lambda-list* {`(declare` {*declaration*}`)`}* {*form*}*`)`

defined in the lexical environment in which the `defun` form was executed (because `defun` forms normally appear at top level, this is normally the null lexical environment).

If the optional documentation string *doc-string* is present (it may be present only if at least one *form* is also specified, as it is otherwise taken to be a *form*), then it is put on the property list of the symbol *name* under the indicator `documentation` (see `putpr`). By convention, if the string contains multiple lines then the first line should be a complete summarizing sentence on which the remainder expands.

Other implementation-dependent bookkeeping actions may be taken as well by `defun`. The *name* is returned as the value of the `defun` form.

For example:

```
(defun discriminant (a b c)
  (declare (number a b c))
  "Compute the discriminant for a quadratic equation.
Given arguments a, b, and c, the value b^2-4*a*c is calculated.
A quadratic equation has real, multiple, or complex roots depen
on whether this calculated value is positive, zero, or negative
  (- (* b b) (* 4 a c)))
  => discriminant
  and now (discriminant 1 2/3 -2) => 76/9
```

It is permissible to redefine a function (for example, to install a corrected version of an incorrect definition!). It is not permissible to define as a function any symbol in use as the name of a special form or macro. To redefine a macro name as the name of a function, `fmakunbound` (page 40) must first be applied to the symbol.

??? Query: What do people think of this safety feature? The error handler could offer to do the `fmakunbound` for you and retry.

Silly ?

3.3.2. Defining Macros

Macros are usually defined by using the special form `defmacro` (page DEFMACRO-FUN). This facility is fairly complicated, and is described in a separate chapter.

3.3.3. Declaring Global Variables and Named Constants

`defvar` *name* [*initial-value* [*documentation*]] [*Special form*]

`defvar` is the recommended way to declare the use of a special variable in a program. It is normally used only as a top-level form.

```
(defvar variable)
```

declares `variable` to be `special` (see `declare` (page 72)), and may perform other system-dependent bookkeeping actions. If a second "argument" is supplied:

```
(defvar variable initial-value)
```

then `variable` is initialized to the result of evaluating the form *initial-value* unless it already has a value. *initial-value* is not evaluated unless it is used; this is useful if it does something expensive like creating a large data structure. The initialization is performed by assignment, and so assigns the variable a global value unless there are currently special bindings of that variable.

`defvar` should be used only at top level, never in function definitions, ~~and only for free variables used by more than one function.~~

`defvar` also provides a good place to put a comment describing the meaning of the variable (whereas an ordinary `special` declaration offers the temptation to declare several variables at once and not have room to describe them all). This can be a simple LISP comment:

```
(defvar tv-height 768)  ;Height of TV screen in pixels.
```

or, better yet, a third "argument" to `defvar`, in which case various programs can access the documentation:

```
(defvar tv-height 768 "Height of TV screen in pixels")
```

The documentation should be a string.

`defconst` *name initial-value* [*documentation*] [*Special form*]

`defconst` is similar to `defvar`, but declares a global variable whose value is "constant". An initial value is always given to the variable. It is an error if there are currently any special bindings of the variable (but implementations may or may not check for this).

If the variable is already has a value, an error occurs unless the existing value is `equal` (page 32) to the specified ~~*initial-value*~~.

Implementation note: Actually, a specific interaction should occur in which the user is asked whether it is permissible to alter the constant. Perhaps there should be some mechanism to discover who uses the constant.

Rationale: `defconst` declares a constant, whose value will "never" be changed. Other code may depend on this fact. On the other hand, `defvar` declares a global variable, whose value is initialized to something but will then be changed by the functions that use it to maintain some state.

Once a symbol has been declared by `defconst` to be constant, ~~no~~ further assignments or bindings of that variable are ~~permitted~~. This is the case for such system-supplied constants as `t` and `max-fixnum`.

(the value of the initial-value form)

rom

Top-level only?

errors

DEFCONSTs can be compiled in.
(But eq/ness must be preserved.)

A big example.
The def convention.

defsetf
defstruct

Chapter 4

Predicates

A *predicate* is a function which tests for some condition involving its arguments and returns ( ) if the condition is false, or some non-( ) value if the condition is true. One may think of a predicate as producing a Boolean value, where ( ) stands for *false* and anything else stands for *true*. Conditional control structures such as `cond` (page 45), `if` (page 46), `when` (page 46), and `unless` (page 47) test such Boolean values. We say that a predicate *is true* when it returns a non-( ) value, and *is false* when it returns ( ); that is, it is true or false according to whether the condition being tested is true or false.

By convention, the names of predicates usually end in the letter "p" (which stands for "predicate").

The control structures which test Boolean values only test for whether or not the value is ( ), which is considered to be false. Any other value is considered to be true. A function which returns ( ) if it "fails" and some *useful* value when it "succeeds" is called a *pseudo-predicate*, because it can be used not only as a test but also for the useful value provided in case of success. An example of a pseudo-predicate is `member` (page 97).

4.1. Data Type Predicates

Perhaps the most important predicates in LISP are those which test for data types; that is, given a data object one can determine whether or not it belongs to a given type.

In COMMON LISP, types are named by LISP objects, specifically symbols and lists. The type symbols defined by the system include:

```
null            cons            list            symbol
vector          string          bit-string      array
function        structure       random          character
number          stream          float           string-char
integer         fixnum          bignum          bit
short-float     single-float    double-float    long-float
complex         ratio           readtable       package
sequence
```

In addition, when a structure type is defined using `defstruct` (page 167), the name of the structure type becomes a valid type symbol.

If the name of a type is a list, the *car* of the list is a symbol, and the rest of the list is subsidiary type information. As a general rule, any subsidiary item may be replaced by ?, or simply omitted if it is the last item of the list; in any of these cases the item is said to be unspecified.

List names of type generally refer to *specializations* of data types named by symbols. These specializations may be reflected by more efficient representations in the underlying implementation. As an example, consider the type `(vector short-float)`. Implementation A may choose to provide a specialized representation for vectors of short floating-point numbers, and implementation B may choose not to. If you should want to create a vector for the express purpose of holding only short-float objects, you may optionally specify to `make-vector` (page 155) the element type `short-float`, meaning, "Produce the most specialized vector representation capable of holding short-floats which the implementation can provide." Implementation A will then produce a specialized short-float vector, and implementation B will produce an ordinary vector (one of type `(vector t)`).

If one were then to ask whether the vector were actually of type `(vector short-float)`, both implementations could properly say "yes"; implementation B might or might not verify that the vector actually contained short-floats. On the other hand, implementation A, if asked whether a vector of type `(vector t)` were of type `(vector short-float)`, it could properly say "no" without even checking the contents of the vector. All this is a bit tricky, but is designed to allow some implementations to provide efficient specialized representations without having to burden all implementations with irrelevant specialized data types.

The valid list-format names for data types are:

- `(array` *type dimensions*`)`: a specialized array whose elements are all members of the type *type* and whose dimensions match *dimensions*. To be more precise, this type encompasses those arrays which can result by specifying *type* to the function `make-array` (page 159). *type* must be a valid type label. *dimensions* may be a non-negative integer, which is the number of dimensions, or it may be a list of non-negative integers representing the length of each dimension (any given dimensions may be unspecified).

  For example:

```
(array integer 3)          ;Three-dimensional arrays of integers.
(array integer (? ? ?))    ;Three-dimensional arrays of integers.
(array ? (4 5 6))          ;4-by-5-by-6 arrays.
(array character (3 ?))    ;Two-dimensional arrays of characters
                           ;   which have exactly three rows.
(array short-float ())     ;Zero-rank arrays of short floating-point numbers.
```

- `(vector` *type size*`)`: a specialized vector (a one-dimensional array with no fill pointer and no displacement) whose elements are all members of the type *type* and which is of length *size*. To be more precise, this type encompasses those vectors which can result by specifying *type* to the function `make-array` (page 159). *size* must be a non-negative integer, and *type* a valid type label. If *type* is unspecified then `t` is assumed (components may be of any type); if *size* is unspecified, then vectors of all sizes are included.

  For example:

```
(vector double-float)     ; Vectors of double-format floating-point numbers.
(vector ? 5)              ; Vectors of length 5.
(vector (mod 32) ?)       ; Vectors of integers between 0 and 31.
```

The types `(vector string-char)` and `(vector bit)` are so useful that they have the special names `string` and `bit-string`; every COMMON LISP implementation must provide these as distinct data types.

> Rationale: NIL had been using the name `bits` for a bit vector. This tended to lead to awkward prose: one had to speak of "a `bits`". The singular noun `bit-vector` is easier to discuss.

- `(integer` *low high*`)`: any integer between *low* and *high*. The limits *low* and *high* must each be an integer, a list of an integer, or `()`; an integer is an inclusive limit, a list of an integer is an exclusive limit, and `()` means that a limit does not exist and so effectively denotes minus or plus infinity, respectively. The type `fixnum` is simply a name for `(integer` *smallest largest*`)` for implementation-dependent values of *smallest* and *largest*. The type `(integer 0 1)` is so useful that it has the special name `bit`.

- `(mod` *n*`)`: a non-negative integer less than *n*. This is equivalent to `(integer 0` *n*`)` or (what is the same thing) `(integer 0 (`*n*`))`.

- `(signed-byte` *s*`)`: equivalent to `(integer` -2^{s-1} $2^{s-1}-1$`)`.

- `(unsigned-byte` *s*`)`: equivalent to `(mod` 2^s`)`, that is, `(integer 0` 2^s-1`)`.

- `(float` *low high*`)`: any floating-point number between *low* and *high*. The limits *low* and *high* must each be a floating-point number, a list of a floating-point number, or `()`; a floating-point number is an inclusive limit, a list of a floating-point number is an exclusive limit, and `()` means that a limit does not exist and so effectively denotes minus or plus infinity, respectively. As examples, the result of the cosine function may be described as being of type `(float -1.0 1.0)`, and the argument to the logarithm function must be of type `(float (0.0) ())`.

  In a similar manner one may use `(short-float` *low high*`)`, `(single-float` *low high*`)`, `(double-float` *low high*`)`, or `(long-float` *low high*`)`; the limits must be floating-point numbers of the appropriate type.

- `(complex` *rtype itype*`)`: a complex number whose real part is of type *rtype* and whose imaginary part is of type *itype*. To be more precise, this type encompasses all those complex numbers which can result by giving arguments of the specified types to the function `complex` (page 130). In a break with the usual convention on omitted items, if *itype* is omitted then it is taken to be the same as *rtype*. As examples, gaussian integers might be described as `(complex integer)`, and the result of the complex logarithm function might be described as being of type `(complex float (float #.(- pi) #.pi))`.

- `(function (`*arg1-type arg2-type ...*`)` *value1-type value2-type ...*`)`: this specifies a function which accepts arguments at *least* of the types specified by the *argj-type* forms, and returns values which are members of the types specified by the *valuej-type* forms. The `&optional` and `&rest` keywords may appear in either list of types. As an example, the function `cons` is of type `(function (t t) cons)`, because it can accept any two arguments and always returns a cons. It is also of type `(function (float string) list)`, because it can certainly accept a floating-point number and a string (among other things), and its result is always

of type `list` (in fact a `cons` and never `null`, but that does not matter for this type determination).

- `(oneof` *object1 object2 ...*`)`: a name for a type containing precisely those objects named. An object is of this type if and only if it is `eql` (page 31) to one of the specified objects.
- `(not` *type*`)`: all those objects which are *not* of the specified type.
- `(or` *type1 type2 ...*`)`: the union of the specified types. For example, the type `list` by definition is the same as `(or null cons)`. Also, the value returned by the function `position` (page 80) is always of type `(or null (integer 0 ()))` (either `()` or a non-negative integer).
- `(and` *type1 type2 ...*`)`: the intersection of the specified types.

Subtype fn.

`typep` *object* `&optional` *type* [*Function*]

`(typep` *object type*`)` is a predicate which is true if *object* is of type *type*, and is false otherwise. Note that an object can be "of" more than one type, since one type can include another. The *type* may be any of the type names mentioned above.

Error signalled if cannot determine?

`(typep` *object*`)` returns an implementation-dependent result: some *type* of which the *object* is a member. Implementations are encouraged to return the most specific type which can be conveniently computed and is likely to be useful to the user. It is required that if the argument is a named structure created by `defstruct` then `typep` will return the name of that structure and not the symbol `structure`. Because the result is implementation-dependent, it is usually better to use `typep` of one argument primarily for debugging purposes, and to use `typep` of two arguments or the `typecase` (page 48) special form in programs.

4.1.1. Specific Data Type Predicates

Should some of these return arg?

The following predicates are for testing for individual data types.

`null` *object* [*Function*]

`null` is true if its argument is `()`, and otherwise is false. This is the same operation performed by the function `not` (page 34); however, `not` is normally used to invert a Boolean value, while `null` is normally used to test for an empty list. The programmer can therefore express *intent* by the choice of function name.

```
(null x) <=> (typep x 'null) <=> (eq x '())
```

`symbolp` *object* [*Function*]

`symbolp` is true if its argument is a symbol, and otherwise is false.

```
(symbolp x) <=> (typep x 'symbol)
```

Compatibility note: In most LISP dialects, including MACLISP, INTERLISP, and even LISP 1.5, `()` is in fact represented by the symbol `nil`, and therefore `(symbolp '())` is true. This association of a symbol with the

empty list has caused problems. Programmers are advised to write code in such a way as not to depend on `()` and `nil` being either the same or not the same, if possible.

`atom` *object* [*Function*]

The predicate `atom` is true if its argument is not a cons, and otherwise is false. It is the inverse of `consp`. Note that `(atom '())` is true.

```
(atom x) <=> (typep x 'atom) <=> (not (typep x 'cons))
```

`consp` *object* [*Function*]

The predicate `consp` is true if its argument is a cons, and otherwise is false. It is the inverse of `atom`. Note that `(consp '()) => ()`.

```
(consp x) <=> (typep x 'cons) <=> (not (typep x 'atom))
```

Compatibility note: Some LISP implementations call this function `pairp` or `listp`. The name `pairp` was rejected for COMMON LISP because it emphasizes too strongly the dotted-pair notion rather than the usual usage of conses in lists. On the other hand, `listp` too strongly implies that the cons is in fact part of a list, which after all it might not be; moreover, `()` is a list, though not a cons. The name `consp` seems to be the appropriate compromise.

`listp` *object* [*Function*]

`listp` is true if its argument is a cons or the empty list `()`, and otherwise is false. It does not check for whether the list is a "true list" (one terminated by `()`) or a "dotted list" (one terminated by a non-null atom).

```
(listp x) <=> (typep x 'list) <=> (typep x '(cons null))
```

Compatibility note: Lisp Machine LISP defines `listp` to mean the same as `pairp`, but this is under review. The definition given here is that adopted by NIL.

`numberp` *object* [*Function*]

`numberp` is true if its argument is any kind of number, and otherwise is false.

```
(numberp x) <=> (typep x 'number)
```

`integerp` *object* [*Function*]

`integerp` is true if its argument is an integer, and otherwise is false.

```
(integerp x) <=> (typep x 'integer)
```

Compatibility note: In MACLISP this is called `fixp`. Users have been confused as to whether this meant "`integerp`" or "`fixnump`", and so these names have been adopted here.

`rationalp` *object* [*Function*]

`rationalp` is true if its argument is a rational number (a ratio or an integer), and otherwise is false.

```
(rationalp x) <=> (typep x 'rational)
```

`floatp` *object* [*Function*]

`floatp` is true if its argument is a floating-point number, and otherwise is false.

```
(floatp x) <=> (typep x 'float)
```

`characterp` *object* [*Function*]

`characterp` is true if its argument is a character, and otherwise is false.

```
(characterp x) <=> (typep x 'character)
```

`stringp` *object* [*Function*]

`stringp` is true if its argument is a string, and otherwise is false.

```
(stringp x) <=> (typep x 'string)
```

`vectorp object` [*Function*]

`vectorp` is true if its argument is a vector, and otherwise is false.

```
(vectorp x) <=> (typep x 'vector)
```

`arrayp` *object* [*Function*]

`arrayp` is true if its argument is an array, and otherwise is false.

```
(arrayp x) <=> (typep x 'array)
```

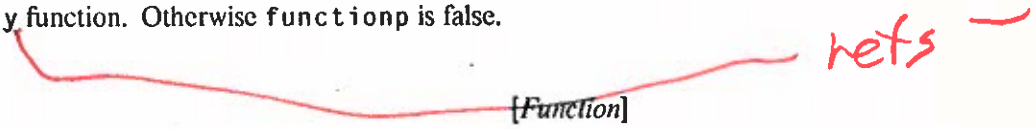
`structurep object` [*Function*]

`structurep` is true if its argument is a structure, and otherwise is false.

```
(structurep x) <=> (typep x 'structure)
```

`functionp` *object* [*Function*]

`functionp` is true if its argument is suitable for applying to arguments, using for example the `funcall` or `apply` function. Otherwise `functionp` is false.



`subrp` *object* [*Function*]

`subrp` is true if its argument is any compiled code object, and otherwise is false.

```
(subrp x) <=> (typep x 'subr)
```

`closurep` *object* [*Function*]

`closurep` is true if its argument is a closure, and otherwise is false.

4.2. Equality Predicates

COMMON LISP provides a spectrum of predicates for testing for equality of two objects: `eq` (the most specific), `eql`, `equal`, and `equalp` (the most general). `eq` and `equal` have the meanings traditional in LISP. `eql` was added because it is frequently needed, and `equalp` was added primarily to complement the arithmetic comparison predicates `lessp` (page LESSP-FUN) and `greaterp` (page GREATERP-FUN). If two objects satisfy any one of these equality predicates, then they also satisfy all those which are more general.

`eq x y` [*Function*]

`(eq x y)` is true if and only if *x* and *y* are the same identical object. (Implementationally, *x* and *y* are usually `eq` if and only if they address the same identical memory location.)

It should be noted that things that print the same are not necessarily `eq` to each other. Symbols with the same print name usually are `eq` to each other, because of the use of the `intern` (page INTERN-FUN) function. However, numbers with the same value need not be `eq`, and two similar lists are usually not `eq`.

For example:

```
(eq 'a 'b) is false
(eq 'a 'a) is true
(eq 3 3) might be true or false, depending on the implementation
(eq 3 3.0) is false
(eq (cons 'a 'b) (cons 'a 'c)) is false
(eq (cons 'a 'b) (cons 'a 'b)) is false
(setq x '(a . b)) (eq x x) is true
(eq #\A #\A) might be true or false, depending on the implementation
(eq "Foo" "Foo") is false
(eq "FOO" "foo") is false
```

Implementation note: `eq` simply compares the two pointers given it, so any kind of object which is represented in an "immediate" fashion will indeed have like-valued instances satisfy `eq`. On the PERQ, for example, fixnums and characters happen to "work". However, no program should depend on this, as other implementations of COMMON LISP might not use an immediate representation for these data types.

`eql x y` [*Function*]

The `eql` predicate is true if its arguments are `eq`, or if they are numbers of the same type with the same value (that is, they are `=` (page 118)), or if they are character objects which represent the same character (that is, they are `char=` (page 142)).

For example:

```
(eql 'a 'b) is false
(eql 'a 'a) is true
(eql 3 3) is true
(eql 3 3.0) is false
(eql (cons 'a 'b) (cons 'a 'c)) is false
(eql (cons 'a 'b) (cons 'a 'b)) is false
(setq x '(a . b)) (eql x x) is true
(eql #\A #\A) is true
(eql "Foo" "Foo") is false
(eql "FOO" "foo") is false
```

`equal` *x y* [*Function*]

The `equal` predicate is true if its arguments are similar (isomorphic) objects. A rough rule of thumb is that two objects are `equal` if and only if their printed representations are the same.

Numbers and characters are compared as for `eql`. Symbols are compared as for `eq`. This can violate the rule of thumb about printed representations, but only in the case of two distinct symbols with the same print name, and this does not ordinarily occur.

Objects which have components are `equal` if they are of the same type and corresponding components are `equal`. This test is implemented in a recursive manner, and will fail to terminate for circular structures. For conses, `equal` is defined recursively as the two *car*'s being `equal` and the two *cdr*'s being `equal`.

Two arrays are `equal` if and only if they have the same number of dimensions, the dimensions match, the element types match, and the corresponding components are `equal`.

> **Compatibility note:** In Lisp Machine Lisp, `equal` ignores the difference between upper and lower case in strings. This violates the rule of thumb about printed representations, however, which is very useful, especially to novices. It is also inconsistent with the treatment of single characters, which are represented as fixnums.

For example:

```
(equal 'a 'b) is false
(equal 'a 'a) is true
(equal 3 3) is true
(equal 3 3.0) is false
(equal (cons 'a 'b) (cons 'a 'c)) is false
(equal (cons 'a 'b) (cons 'a 'b)) is true
(setq x '(a . b)) (equal x x) is true
(equal #\A #\A) is true
(equal "Foo" "Foo") is true
(equal "FOO" "foo") is false
```

To recursively compare only conses, and compare all atoms using `eq`, use `tree-equal` (page 88).

`equalp` *x y* `&optional` *fuzz* [*Function*]

Two objects are `equalp` if they are `eql`, if they are characters and differ only in alphabetic case (that is, they are `char-equal` (page 142)), if they are numbers and have the same numerical value, even if they are of different types, or if they have components which are all `equalp`. By this latter characteristic `equalp` complements `tessp` (page 11.ISSP-FUN) and `greaterp` (page

GREATERP-FUN), which perform inequality comparisons among numbers of possibly differing types. When comparing floating-point numbers, or comparing a floating-point number to any other kind of number, the optional argument *fuzz* is used. Two numbers are considered to be equal if the absolute value of their difference is no greater than *fuzz* times the absolute value of the one with the larger absolute value; that is, x and y are considered equal if $abs(x-y) \leq fuzz * max(abs(x), abs(y))$. If no third argument is supplied, then *fuzz* defaults to `0.0`, and in this case x and y must be exactly equal for `equalp` to be true. (See the function = (page 118).)

Objects which have components are `equalp` if they are of the same type and corresponding components are `equalp`. This test is implemented in a recursive manner, and will fail to terminate for circular structures. For conses, `equalp` is defined recursively as the two *car*'s being `equalp` and the two *cdr*'s being `equalp`.

Two arrays are `equalp` if and only if they have the same number of dimensions, the dimensions match, the element types match, and the corresponding components are `equalp`.

??? Query: How about eliminating the clause "the element types match" from the above specification? This would allow a string and a general array that happens to contain character to be `equalp`, for example.

For example:

```
(equalp 'a 'b) is false
(equalp 'a 'a) is true
(equalp 3 3) is true
(equalp 3 3.0) is true
(equalp (cons 'a 'b) (cons 'a 'c)) is false
(equalp (cons 'a 'b) (cons 'a 'b)) is true
(setq x '(a . b)) (equalp x x) is true
(equalp #\A #\A) is true
(equalp "Foo" "Foo") is true
(equalp "FOO" "foo") is true
```

4.3. Logical Operators

COMMON LISP provides three operators on Boolean values: `and`, `or`, and `not`. Of these, `and` and `or` are also control structures, because their arguments are evaluated conditionally. `not` necessarily examines its single argument, and so is a simple function.

`not` *x* [*Function*]

`not` is true if x is `()`, and otherwise is false. It therefore inverts its argument, interpreted as a Boolean value.

`null` (page 36) is the same as `not`; both functions are included for the sake of clarity. As a matter of style, it is customary to use `null` to check whether something is the empty list, and to use `not` to invert the sense of a logical value.

`and` {*form*}* [*Special form*]

`(and` *form1 form2* `...` `)` evaluates each *form*, one at a time, from left to right. If any *form* evaluates to `()`, `and` immediately is false without evaluating the remaining *forms*. If every *form* but the last evaluates to a non-`()` value, `and` returns whatever the last *form* returns. Therefore in general `and` can be used both for logical operations, where `()` stands for *false* and non-`()` values stand for *true*, and as a conditional expression.

For example:

```
(if (and (>= n 0.)
         (lessp n (length a-vector))
         (eq (vref a-vector n) 'foo))
    (princ "Foo!"))
```

The above expression prints "`Foo!`" if element `n` of `a-vector` is the symbol `foo`, provided also that `n` is indeed a valid index for `a-vector`. Because `and` guarantees left-to-right testing of its parts, `vref` is not performed if `n` is out of range. (In this example writing

```
(and (>= n 0)
     (lessp n (length a-vector))
     (eq (vref a-vector n) 'foo)
     (princ "Foo!"))
```

would accomplish the same thing; the difference is purely stylistic.) Because of the guaranteed left-to-right ordering, `and` is like the **and then** operator in ADA, rather than the **and** operator.

See also `if` (page 46) and `when` (page 46), which are sometimes stylistically more appropriate than `and` for conditional purposes.

From the general definition, one can deduce that `(and` *x*`)` `<=>` *x*. Also, `(and)` is true, which is an identity for this operation.

`and` can be defined in terms of `cond` (page 45) as follows:

```
(and x y z ... w) <=>
   (cond ((not x) ())
         ((not y) ())
         ((not z) ())
         ...
         (t w))
```

`or` {*form*}* [*Special form*]

`(or` *form1 form2* `...` `)` evaluates each *form*, one at a time, from left to right. If any *form* evaluates to something other than `()`, `or` immediately returns it without evaluating the remaining *forms*. If every *form* but the last evaluates to `()`, `or` returns whatever evaluation of the last of the *forms* returns. Therefore in general `or` can be used both for logical operations, where `()` stands for *false* and non-`()` values stand for *true*, and as a conditional expression. Because of the guaranteed left-to-right ordering, `or` is like the **or else** operator in ADA, rather than the **or** operator.

See also `if` (page 46) and `unless` (page 47), which are sometimes stylistically more appropriate than `or` for conditional purposes.

From the general definition, one can deduce that `(or x)` <=> *x*. Also, `(or)` is false, which is the identity for this operation.

`or` can be defined in terms of `cond` (page 45) as follows:

```
(or x y z ... w) <=>
   (cond (x) (y) (z) ... (t w))
```

Chapter 5

Control Structure

LISP provides a variety of special structures for organizing programs. Some have to do with flow of control (control structures), while others control access to variables (environment structures). Most of these features are implemented either as special forms or as macros (which typically expand into complex program fragments involving special forms).

Function application is the primary method for construction of LISP programs. Operations are written as the application of a function to its arguments. Usually, LISP programs are written as a large collection of small functions, each of which implements a simple operation. These functions operate by calling one another, and so larger operations are defined in terms of smaller ones. LISP functions may call upon themselves recursively, either directly or indirectly.

LISP, while more applicative in style than statement-oriented, nevertheless provides many operations which produce side-effects, and consequently requires constructs for controlling the sequencing of side-effects. The construct `progn` (page 42), which is roughly equivalent to an ALGOL **begin-end** block with all its semicolons, executes a number of forms sequentially, discarding the values of all but the last. Many LISP control constructs include sequencing implicitly, in which case they are said to provide an "implicit `progn`". Other sequencing constructs include `prog1` (page 42) and `prog2` (page 43).

For looping, COMMON LISP provides the general iteration facility `do` (page 49), as well as a variety of special-purpose iteration facilities for iterating or mapping over various data structures.

COMMON LISP provides the simple one-way conditionals `when` and `unless`, the simple two-way conditional `if`, and the more general multi-way conditionals such as `cond` and ~~`selectq`~~. The choice of which form to use in any particular situation is a matter of taste and style.

Non-local exits, binding of temps, multiple values. Eventually make all this in order corresponding to main text.

5.1. Constants and Variables

5.1.1. Reference

`quote` *object* [*Special form*]

`(quote x)` simply returns *x*. The argument is not evaluated, and may be any LISP object. This construct allows any LISP object to be written as a constant value in a program.

For example:

```
(setq a 43)
(list a (cons a 3)) => (43 (43 . 3))
(list (quote a) (quote (cons a 3)) => (a (cons a 3))
```

Since `quote` forms are so frequently useful but somewhat cumbersome to type, a standard abbreviation is defined for them: any form preceded by a single quote (') character is assumed to have "`(quote )`" wrapped around it.

For example:

```
(setq x '(the magic quote hack))
    is normally interpreted when read to mean
(setq x (quote (the magic quote hack)))
```

by the Lisp reader

hey?

`function` *fn* [*Special form*]

The value of `function` is always the functional interpretation of the form *fn*; *fn* is interpreted as if it had appeared in the functional position of a function invocation. In particular, if *fn* is a symbol, the functional value of the variable whose name is that symbol is returned.

Compatibility note: ???

If *fn* is a lambda expression, then a functional object (a lexical closure) is returned.

Since `function` forms are so frequently useful (for passing functions as arguments to other function) but somewhat cumbersome to type, a standard abbreviation is defined for them: any form preceded by a sharp sign and then a single quote (`#'`) is assumed to have "`(function )`" wrapped around it.

For example:

mapcar

```
(rem-if #'numberp '(1 a b 3))
    is normally interpreted when read to mean
(rem-if (function numberp) '(1 a b 3))
```

by the Lisp reader

mapcar

`symeval` *symbol* [*Function*]

dynamic

`symeval` returns the current value of the dynamic (special) variable named by *symbol*. An error occurs if the symbol has no value; see `boundp` (page 39) and `makunbound` (page 40).

lexical

`symeval` cannot access the value of a local (lexically bound) variable.

This function is particularly useful for implementing interpreters for languages embedded in LISP. The corresponding assignment primitive is `set` (page 40).

`fsymeval` *symbol* [*Function*]

`fsymeval` returns the current global function definition named by *symbol*. An error occurs if the symbol has no function definition; see `boundp` (page 39) and `makunbound` (page 40).

`fsymeval` cannot access the value of a local function name (lexically bound as by `flet` (page FLET-FUN) or `labels` (page LABELS-FUN)).

This function is particularly useful for implementing interpreters for languages embedded in LISP. The corresponding assignment primitive is `fset` (page 40).

`boundp` *symbol* [*Function*]

`fboundp` *symbol* [*Function*]

`boundp` is true if the dynamic (special) variable named by *symbol* has a value; otherwise, it returns `()`. `fboundp` is the analogous predicate for the global function definition named by *symbol*.

See also `set` (page 40), `fset` (page 40), `makunbound` (page 40), and `fmakunbound` (page 40).

Compatibility note: I believe that in Lisp Machine LISP `boundp` can manage to refer to a local variable if its argument appears as a quoted constant. If so, it is an incredible hack, and violates the rule that a function cannot tell how its arguments were computed. In COMMON LISP, `boundp` can never refer to a local variable, and `fboundp` can never refer to a local function definition.

5.1.2. Assignment

`setq` {*var form*}* [*Special form*]

The special form `(setq` *var1 form1 var2 form2* `...)` is the "simple variable assignment statement" of Lisp. First *form1* is evaluated and the result is assigned to *var1*, then *form2* is evaluated and the result is assigned to *var2*, and so forth. The variables are represented as symbols, of course, and are interpreted as referring to static or dynamic instances according to the usual rules. `setq` returns the last value assigned, that is, the result of the evaluation of its last argument. As a boundary case, the form `(setq)` is legal and returns `()`. As a rule there must be an even number of argument forms.

For example:

```
(setq x (+ 3 2 1) y (cons x nil))
```

`x` is set to `6`, `y` is set to `(6)`, and the `setq` returns `(6)`. Note that the first assignment was performed before the second form was evaluated, allowing that form to use the new value of `x`.

See also the description of `setf` (page SETF-FUN), which is the "general assignment statement", capable of assigning to variables, array elements, and other locations.

`psetq` {*var form*}* [*Special form*]

A `psetq` form is just like a `setq` form, except that the assignments happen in parallel; first all of the forms are evaluated, and then the variables are set to the resulting values. The value of the `psetq` form is `()`.

For example:

```
(setq a 1)
(setq b 2)
(psetq a b  b a)
a => 2
b => 1
```

see exchf

In this example, the values of a and b are exchanged by using parallel assignment. (Note that the do (page 49) iteration construct performs a very similar thing when stepping iteration variables.)

`set` *symbol value* [*Function*]

`set` allows alteration of the value of a dynamic (special) variable. `set` causes the dynamic variable named by *symbol* to take on *value* as its value. Only the value of the current dynamic binding is altered; if there are no bindings in effect, the most global value is altered.

For example:

```
(set (if (eq a b) 'c 'd) 'foo)
```

will either set c to `foo` or set d to `foo`, depending on the outcome of the test `(eq a b)`.

Both functions return *value* as the result value.

set cannot alter the value of a local (lexically bound) variable. The special form `setq` (page 47) is usually used for altering the values of variables (lexical or dynamic) in programs. `set` is particularly useful for implementing interpreters for languages embedded in LISP. See also `progv` (page 45), a construct which performs binding rather than assignment of dynamic variables.

`fset` *symbol value* [*Function*]

`fset` allows alteration of the global function definition named by *symbol* to be *value*. `fset` returns *value*.

fset cannot alter the value of a local (lexically bound) function definition, as made by `flet` (page FLET-FUN) or `labels` (page LABELS-FUN). ~~The special form `setq` (page 47) is usually used for altering the values of variables (lexical or dynamic) in programs.~~ `fset` is particularly useful for implementing interpreters for languages embedded in LISP.

`makunbound` *symbol* [*Function*]
`fmakunbound` *symbol* [*Function*]

split

`makunbound` causes the dynamic (special) variable named by *symbol* to become unbound (have no value). `fmakunbound` does the analogous thing for the global function definition named by *symbol*.

For example:

```
(setq a 1)
a => 1
(makunbound 'a)
a => causes an error
(defun foo (x) (+ x 1))
(foo 4) => 5
(fmakunbound 'foo)
(foo 4) => causes an error
```

Both functions return *symbol* as the result value.

Compatibility note: I believe that in Lisp Machine LISP `makunbound` can manage to refer to a local variable if its argument appears as a quoted constant. If so, it is an incredible hack, and violates the rule that a function cannot tell how its arguments were computed. In COMMON LISP, `makunbound` can never refer to a local variable, and `fmakunbound` can never refer to a local function definition.

5.2. Generalized Variables

In LISP, a variable can remember one piece of data, a LISP object. The main operations on a variable are to recover that piece of data, and to alter the variable to remember a new object; these operations are often called *access* and *update* operations. The concept of variables named by symbols can be generalized to any storage location that can remember one piece of data, no matter how that location is named. Examples of such storage locations are the *car* and *cdr* of a cons, elements of an array, and components of a structure.

For each kind of generalized variable, there are typically two functions which implement the conceptual *access* and *update* operations. For a variable, merely mentioning the name of the variable accesses it, while the `setq` (page 47) special form can be used to update it. The function `car` (page 87) accesses the *car* of a cons, and the function `rplaca` (page 94) updates it. The function `aref` (page 160) accesses an array element, and the function `aset` (page 160) updates it.

Rather than thinking about two distinct functions that respectively access and update a storage location somehow deduced from their arguments, we can instead simply think of a call to the access function with given arguments as a *name* for the storage location. Thus, just as `x` may be considered a name for a storage location (a variable), so `(car x)` is a name for the *car* of some cons (which is in turn named by `x`), and `(aref a 105)` is a name for element 105 of the array named `a`. Now, rather than having to remember two functions for each kind of generalized variable (having to remember, for example, that `aset` corresponds to `aref`), we adopt a uniform syntax for updating storage locations named in this way, using the `setf` special form. This is analogous to the way we use the `setq` special form to convert the name of a variable (which is also a form which accesses it) into a form which updates it. The uniformity of this approach may be seen from the following table:

Access function	Update function	Update using `setf`
`x`	`(setq x newvalue)`	`(setf x newvalue)`
`(car x)`	`(rplaca x newvalue)`	`(setf (car x) newvalue)`
`(aref a 105)`	`(aset newvalue a 105)`	`(setf (aref a 105) newval`
`(nth n x)`	`(setnth n x newvalue)`	`(setf (nth n x) newvalue)`

`setf` is actually a macro that examines an access form and expands into the appropriate update function.

`setf` *place newvalue* [*Macro*]

`setf` takes a form *place* that when evaluated *accesses* a data object in some location, and "inverts" it to produce a corresponding form to *update* the location. A call to the `setf` macro therefore expands into an update form that stores the result of evaluating the form *newvalue* into the place referred to by the *access-form*.

For example:

```
(setf a 3) ==> (setq a 3)
(setf (plist 'a) '(foo bar)) ==> (setplist 'a '(foo bar))
(setf (aref q 2) 56) ==> (aset 56 q 2)
(setf (cadr w) x) ==> (rplaca (cdr w) x)
```

The form *place* may be any one of the following:

- The name of a variable (either lexical or dynamic).
- A function call form whose first element is the name of any one of the following functions:

```
car
    (page 87)      caaaar
    (page CAAAAR-FUN)                cadddr
    (page CADDDR-FUN)
cdr
    (page 87)      cdaaar
    (page CDAAAR-FUN)                cddddr
    (page CDDDDR-FUN)
caar
    (page CAAR-FUN)                  cadaar
    (page CADAAR-FUN)                elt
    (page 76)
cdar
    (page CDAR-FUN)                  cddaar
    (page CDDAAR-FUN)                nth
    (page 89)
cadr
    (page CADR-FUN)                  caadar
    (page CAADAR-FUN)                vref
    (page 156)
cddr
    (page CDDR-FUN)                  cdadar
    (page CDADAR-FUN)                aref
    (page 160)
caaar
    (page CAAAR-FUN)                 caddar
    (page CADDAR-FUN)                symeval
    (page 46)
cdaar
    (page CDAAR-FUN)                 cdddar
    (page CDDDAR-FUN)                fsymeval
    (page 47)
cadar
    (page CADAR-FUN)                 caaadr
    (page CAAADR-FUN)                getpr
    (page GETPR-FUN)
cddar
    (page CDDAR-FUN)                 cdaadr
    (page CDAADR-FUN)                gethash
    (page 109)
caadr
    (page CAADR-FUN)                 cadadr
    (page CADADR-FUN)                plist
    (page 114)
cdadr
    (page CDADR-FUN)                 cddadr
    (page CDDADR-FUN)
caddr
    (page CADDR-FUN)                 caaddr
    (page CAADDR-FUN)
cdddr
    (page CDDDR-FUN)                 cdaddr
    (page CDADDR-FUN)
```

- A function call form whose first element is the name of a selector function constructed

How does the fit into this?

by `defstruct` (page 167).

- A function call form whose first element is the name of any one of the following functions, provided that the new value is of the specified type so that it can be used to replace the specified "location" (which is in each of these cases not really a truly generalized variable):

Function name	Required type	Update function u
`char`		
`(page 149)`	`string-char`	`rplachar`
`(page 150)`		
`bit`		
`(page 156)`	`(mod 2)rplacbit`	
`(page 156)`		
`subseq`		
`(page 76)`	`sequence`	`replace`
`(page 77)`		

- A function call form whose first element is the name of any one of the following functions, provided that the specified argument to that function is in turn a *place* form; in this case the new *place* has stored back into it the result of applying the specified "update" function (which is in each of these cases not a true update function):

Function name	Argument that is a *place*	Update function us
`char-bit`		
(page CHAR-BIT-FUN)	First	`set-char-bit`
(page SET-CHAR-BIT-FUN)		
`ldb`		
(page 134)	Second	`dpb`
(page 135)		
`mask-field`		
(page 135)	Second	`deposit-field`
(page 135)		

- A macro call, in which case the macro call is expanded and `setf` then analyzes the resulting form.

`setf` carefully arranges to preserve the usual left-to-right order in which the various subforms are evaluated. For example,

```
(setf (aref (compute-an-array) 105) (compute-newvalue))
```

does not expand precisely into

```
(aset (compute-newvalue) (compute-an-array) 105)
```

lest side effects in the computations `(compute-an-array)` and `(compute-newvalue)` occur in the wrong order. Instead this example will expand into something more like

```
(let ((G1 (compute-an-array))
      (G2 105)
      (G3 (compute-newvalue)))
  (aset G3 G1 G2))
```

The exact expansion for any particular form is not guaranteed and may even be implementation-

dependent; all that is guaranteed is that the expansion of a `setf`-form will be an update form that works for that particular implementation, and that the left-to-right evaluation of subforms is preserved.

Compatibility note: Lisp Machine Lisp, at least, officially does not preserve the order of evaluation, but also seems to regard this as a bug to be fixed. ~~What shall Common Lisp do?~~

The ultimate result of evaluating a `setf` form is the value of `newvalue`. (Therefore `(setf (car x) y)` does not expand into precisely `(rplaca x y)`, but into something more like

```
(let ((G1 x) (G2 y)) (rplaca G1 G2) G2)
```

the precise expansion being implementation-dependent.)

Compatibility note: Presently the value of a `setf` form is generally considered to be undefined. Are implementors willing always to return *newvalue*?

The user can define new `setf` expansions by using `defsetf` (page DEFSETF-FUN).

`swapf` *place newvalue* [*Macro*]

The datum in *place* is replaced by *newvalue*, and then the old value of *place* is returned. The form *place* may be any form acceptable as a generalized variable to `setf` (page 50).

For example:

```
(setq x '(a b c))
(swapf (cadr x) 'z) => b
   and now x => (a z c)
```

The effect of `(swapf` *place newvalue*`)` is roughly equivalent to

```
(prog1 place (setf place newvalue))
```

except that the latter would evaluate any subforms of *place* twice, while `swapf` takes care to evaluate them only once.

For example:

```
(setq n 0)
(setq x '(a b c d))
(swapf (nth (setq n (+ n 1)) x) 'z) => b
   and now x => (a z c d)
```

but

```
(setq n 0)
(setq x '(a b c d))
(prog1 (nth (setq n (+ n 1)) x)
       (setf (nth (setq n (+ n 1)) x) 'z)) => b
and now x => (a b z d)
```

Moreover, for certain *place* forms `swapf` may be significantly more efficient than the `prog1` version.

`exchf` *place1 place2* [*Macro*]

The data in *place1* and *place2* are exchanged, and then the old value of *place2* (which has become the new value of *place1*) is returned. The forms *place1* and *place2* may be any forms acceptable as generalized variables to `setf` (page 50). If *place1* and *place2* refer to the same generalized

variable, then the effect is to leave it unchanged and return its value.

For example:

```
(setq x '(a b c))
(exchf (car x) (cadr x)) => b
   and now x => (b a c)
```

The effect of `(exchf` *place1 place2*`)` is roughly equivalent to

```
(setf place1 (prog1 place2 (setf place2 place1)))
```

except that the latter would evaluate any subforms of *place1* and *place2* twice, while `exchf` takes care to evaluate them only once. Moreover, for certain *place* forms `exchf` may be significantly more efficient than the `prog1` version.

Other macros that manipulate generalized variables include `incf` (page INCF-FUN), `decf` (page DECF-FUN), `push` (page 92), and `pop` (page 92).

5.3. Function Invocation

The most primitive form for function invocation in LISP of course has no name; any list which which has no other interpretation as a macro call or special form is taken to be a function call. Other constructs are provided for less common but nevertheless frequently useful situations.

`apply` *function arglist* [*Function*]

This applies *function* to the list of arguments *arglist*. *arglist* should be a list; *function* can be a compiled-code object, or it may be a "lambda expression", that is, a list whose *car* is the symbol `lambda`, or it may a symbol, in which case the dynamic functional value of that symbol is used (but it is illegal in this case for that symbol to be the name of a macro or special form).

For example:

```
(setq f '+) (apply f '(1 2)) => 3
(setq f '-) (apply f '(1 2)) => -1
(apply 'cons '((+ 2 3) 4)) =>
        ((+ 2 3) . 4)   not (5 . 4)
```

Of course, *arglist* may be ( ) (in which case the function is given no arguments.)

Compatibility note: ???

`funcall` *fn* `&rest` *arguments* [*Function*]

`(funcall` *fn a1 a2 ... an*`)` applies the function *fn* to the arguments *a1*, *a2*, ..., *an*. *fn* may not be a special form nor a macro; this would not be meaningful.

For example:

```
(cons 1 2) => (1 . 2)
(setq cons (fsymeval '+))
(funcall cons 1 2) => 3
```

The difference between `funcall` and an ordinary function call is that the function is obtained by

ordinary LISP evaluation rather than by the special interpretation of the function position that normally occurs.

Compatibility note: This corresponds roughly to the INTERLISP primitive `apply*`.

`funcall*` *f* `&rest` *args* [*Function*]

`funcall*` is like a cross between `apply` and `funcall`. (`funcall*` *a1 a2 ... an list*) applies the function *f* to the arguments *a1* through *an* followed by the elements of *list*. Thus we have:

```
(funcall f a1 ... an) <=> (funcall* f a1 ... an '())
(apply f list) <=> (funcall* f list)
```

However, when `apply` or `funcall` fits the situation at hand, it may be stylistically clearer to use that than to use `funcall*`, whose use implies that something more complicated is going on.

```
(funcall* #'+ 1 1 1 '(1 1 1)) => 6

(defun report-error (&rest args)
       (funcall* (function format) error-output args))
```

Compatibility note: ???

5.4. Simple Sequencing

`progn` {*form*}* [*Special form*]

The `progn` construct takes a number of forms and evaluates them sequentially, in order, from left to right. The values of all the forms but the last are discarded; whatever the last form returns is returned by the `progn` form. One says that all the forms but the last are evaluated for *effect*, because their execution is useful only for the side effects caused, but the last form is executed for *value*.

`progn` is the primitive control structure construct for "compound statements"; it is analogous to begin-end blocks in ALGOL-like languages. Many LISP constructs are "implicit `progn`" forms, in that as part of their syntax each allows many forms to be written which are evaluated sequentially, the results of only the last of which are used for anything.

If the last form of the `progn` returns multiple values, then those multiple values are returned by the `progn` form. If there are no forms for the `progn`, then the result is `()`. These rules generally hold for implicit `progn` forms as well.

`prog1` *first* {*form*}* [*Special form*]

`prog1` is similar to `progn`, but it returns the value of its *first* form. All the argument forms are executed sequentially; the value the first form produces is saved while all the others are executed, and is then returned.

`prog1` is most commonly used to evaluate an expression with side effects, and return a value which must be computed *before* the side effects happen.

For example:

```
(prog1 (car x) (rplaca x 'foo))
```

alters the *car* of x to be `foo` and returns the old *car* of `x`.

`prog1` always returns a single value, even if the first form tries to return multiple values. A consequence of this is that `(prog1 x)` and `(progn x)` may behave differently if *x* can produce multiple values. See `mvprog1` (page 60).

`prog2` *first second* {*form*}* [*Special form*]

`prog2` is similar to `prog1`, but it returns the value of its *second* form. All the argument forms are executed sequentially; the value of the second form is saved while all the other forms are executed, and is then returned.

`prog2` is provided ~~mostly~~ for historical compatibility.

```
(prog2 a b c ... z) <=> (progn a (prog1 b c ... z))
```

Occasionally it is desirable to perform one side effect, then a value-producing operation, then another side effect; in such a peculiar case `prog2` is fairly perspicuous.

For example:

```
(prog2 (open-a-file) (compute-on-file) (close-the-file))
  ;value is that of compute-on-file
```

`prog2`, like `prog1`, always returns a single value, even if the second form tries to return multiple values. A consequence of this is that `(prog2 x y)` and `(progn x y)` may behave differently if *y* can produce multiple values.

5.5. Environment Manipulation

`let` `({`*var* `|` `(`*var value*`)}*)` {*form*}* [*Macro*]

A `let` form can be used to execute a series of forms with specified variables bound to specified values.

For example:

```
(let ((var1 value1)
      (var2 value2)
      ...
      (varm valuem))
  body1
  body2
  ...
  bodyn)
```

first evaluates the expressions *value1*, *value2*, and so on, in that order, saving the resulting values. Then all of the variables *varj* are bound to the corresponding values in parallel; each binding will be a local binding unless there is a `special` (page 72) declaration to the contrary. The expressions *bodyj* are then evaluated in order; the values of all but the last are discarded (that is, the

body of a `let` form is an implicit `progn`). The `let` form returns what evaluating *bodyn* produces (if the body is empty, which is fairly useless, `let` returns `()` as its value). The bindings of the variables disappear when the `let` form is exited.

Instead of a list (*varj valuej*) one may write simply *varj*. In this case *varj* is initialized to `()`. As a matter of style, it is recommended that *varj* be written only when that variable will be stored into (such as by `setq` (page 47)) before its first use. If it is important that the initial value is `()` rather than some undefined value, then it is clearer to write out (*varj* `()`) or (*varj* `'()`).

Declarations may appear at the beginning of the body of a `let`; they apply to the code in the body *and* to the bindings made by `let`, but not to the code which produces values for the bindings.

The `let` form shown above is entirely equivalent to:

```
((lambda (var1 var2 ... varn)
         body1 body2 ... bodyn)
 value1 value2 ... valuem)
```

but `let` allows each variable to be textually close to the expression which produces the corresponding value, thereby improving program readability.

`let*` ({*var* | (*var value*)}*) {*form*}* [*Special form*]

`let*` is similar to `let` (page 56), but the bindings of variables are performed sequentially rather than in parallel. This allows the expression for the value of a variable to refer to variables previously bound in the `let*` form.

More precisely, the form:

```
(let* ((var1 value1)
       (var2 value2)
       ...
       (varn valuem))
      body1
      body2
      ...
      bodyn)
```

first evaluates the expression *value1*, then binds the variable *var1* to that value; then its evaluates *value2* and binds *var2*; and so on. The expressions *bodyj* are then evaluated in order; the values of all but the last are discarded (that is, the body of a `let*` form is an implicit `progn`). The `let*` form returns the results of evaluating *bodyn* (if the body is empty, which is fairly useless, `let*` returns `()` as its value). The bindings of the variables disappear when the `let*` form is exited.

Instead of a list (*varj valuej*) one may write simply *varj*. In this case *varj* is initialized to `()`. As a matter of style, it is recommended that *varj* be written only when that variable will be stored into (such as by `setq` (page 47)) before its first use. If it is important that the initial value is `()` rather than some undefined value, then it is clearer to write out (*varj* `()`) or (*varj* `'()`).

Declarations may appear at the beginning of the body of a `let`; they apply to the code in the body *and* to the bindings made by `let`, but not to the code which produces values for the bindings.

`progv` *symbols values* {*form*}*. [*Special form*]

`progv` is a special form which allows binding one or more dynamic variables whose names may be determined at run time. The sequence of forms (an implicit `progn`) is evaluated with the dynamic variables whose names are in the list *symbols* bound to corresponding values from the list *values*. (If too few values are supplied, the remaining symbols are bound to `()`. If too many values are supplied, the excess values are ignored.) The results of the `progv` form are those of the last *form*. The bindings of the dynamic variables are undone on exit from the `progv` form. The lists of symbols and values are computed quantities; this is what makes `progv` different from, for example, `let` (page 56), where the variable names are stated explicitly in the program text.

`progv` is particularly useful for writing interpreters for languages embedded in LISP; it provides a handle on the mechanism for binding dynamic variables.

5.6. Conditionals

`cond` {(*test* {*form*}*)}* [*Special form*]

The `cond` special form takes a number (possibly zero) of *clauses*, which are lists of forms. Each clause consists of a *test* followed by zero or more *consequents*.

For example:

```
(cond (test-1 consequent-1-1 consequent-1-2 ...)
      (test-2)
      (test-3 consequent-3-1 ...)
      ... )
```

The first clause whose *test* evaluates to non-`()` is selected; all other clauses are ignored, and the consequents of the selected clause are evaluated in order (as an implicit `progn`).

More specifically, `cond` processes its clauses in order from left to right. For each clause, the *test* is evaluated. If the result is `()`, `cond` advances to the next clause. Otherwise, the *cdr* of the clause is treated as a list of forms, or consequents, which are evaluated in order from left to right, as an implicit `progn`. After evaluating the consequents, `cond` returns without inspecting any remaining clauses. The `cond` special form returns the results of evaluating the last of the selected consequents; if there were no consequents in the selected clause, then the single (and necessarily non-null) value of the *test* is returned. If `cond` runs out of clauses (every test produced `()`, and therefore no clause was selected), the value of the `cond` form is `()`.

If it is desired to select the last clause unconditionally if all others fail, the standard convention is to use `t` for the *test*. As a matter of style, it is desirable to write a last clause "`(t ())`" if the value of the *cond* form is to be used for something. Similarly, it is in questionable taste to let the last clause of a `cond` be a "singleton clause"; an explicit `t` should be provided. (Note moreover that `(cond ... (x))` may behave differently from `(cond ... (t x))` if *x* might produce multiple values; the former always returns a single value, while the latter returns whatever values *x* returns.)

For example:

```
(setq z (cond (a 'foo) (b 'bar)))          ;Possibly confusing.
(setq z (cond (a 'foo) (b 'bar) (t ())))   ;Better.
(cond (a b) (c d) (e))                     ;Possibly confusing.
(cond (a b) (c d) (t e))                   ;Better.
(cond (a b) (c d) (t (values e)))          ;Better (if one value is neede
(cond (a b) (c))                           ;Possibly confusing.
(cond (a b) (t c))                         ;Better.
(if a b c)                                 ;Also better.
```

A LISP `cond` form may be compared to a continued **if-then-elseif** as found in many algebraic programming languages:

```
(cond (p ...)                    roughly corresponds to    if p then ...
      (q ...)                                              else if q then ...
      (r ...)                                              else if r then ...
      ...                                                  ...
      (t ...))                                             else ...
```

`if` *pred then* [*else*] [*Special form*]

The `if` special form corresponds to the **if-then-else** construct found in most algebraic programming languages. First the form *pred* is evaluated. If the result is not `()`, then the form *then* is selected; otherwise the form *else* is selected. Whichever form is selected is then evaluated, and `if` returns whatever evaluation of the selected form returns.

`(if` *pred then else*`)` `<=>` `(cond (`*pred then*`) (t` *else*`))`

but `if` is considered more readable in some situations.

The *else* form may be omitted, in which case if the value of *pred* is `()` then nothing is done and the value of the `if` form is `()`. If the value of the `if` form is important in this situation, then the `and` (page 42) construct may be stylistically preferable, depending on the context. If the value is not important, but only the effect, then the `when` (page 46) construct may be stylistically preferable.

`when` *pred* {*form*}* [*Special form*]

`(when` *pred form1 form2 ...* `)` first evaluates *pred*. If the result is `()`, then no *form* is evaluated, and `()` is returned. Otherwise the *forms* constitute an implicit `progn`, and so are evaluated sequentially from left to right, and the value of the last one is returned.

```
(when p a b c) <=> (and p (progn a b c))
(when p a b c) <=> (cond (p a b c))
(when p a b c) <=> (if p (progn a b c) '())
(when p a b c) <=> (unless (not p) a b c)
```

As a matter of style, `when` is normally used to conditionally produce some side effects, and the value of the `when`-form is normally not used. If the value is relevant, then `and` (page 42) or `if` (page 46) may be stylistically more appropriate.

`unless` *pred* {*form*}* [*Special form*]

`(unless` *pred form1 form2 ...* `)` first evaluates *pred*. If the result is *not* `( )`, then the *forms* are not evaluated, and `( )` is returned. Otherwise the *forms* constitute an implicit `progn`, and so are evaluated sequentially from left to right, and the value of the last one is returned.

```
(unless p a b c) <=> (cond ((not p) a b c))
(unless p a b c) <=> (if p '() (progn a b c))
(unless p a b c) <=> (when (not p) a b c)
```

As a matter of style, `unless` is normally used to conditionally produce some side effects, and the value of the `unless`-form is normally not used. If the value is relevant, then `or` (page 42) or `if` (page 59) may be stylistically more appropriate.

`case` *keyform* {(({*key*}*) {*form*}*)}* [*Special form*]

`case` is a conditional which chooses one of its clauses to execute by comparing a value to various constants, which are typically keyword symbols, integers, or characters (but may be any objects). Its form is as follows:

```
(case keyform
  (keylist-1 consequent-1-1 consequent-1-2 ...)
  (keylist-2 consequent-2-1 ...)
  (keylist-3 consequent-3-1 ...)
  ...)
```

Structurally `case` is much like `cond` (page 58), and it behaves like `cond` in selecting one clause and then executing all consequents of that clause. It differs in the mechanism of clause selection.

The first thing `case` does is to evaluate the form *keyform* to produce an object called the *key object*. Then `case` considers each of the clauses in turn. If *key* is in the *keylist* (that is, is `eql` to any item in the *keylist*) of a clause, the consequents of that clause are evaluated as an implicit `progn`, and `case` returns what was returned by the last consequent (or `( )` if there are no consequents in that clause). If no clause is satisfied, `case` returns `( )`.

Instead of a *keylist*, one may write ~~one of the symbols~~ `t` ~~and~~ `otherwise`. A clause with such a symbol always succeed, and must be the last clause.

> Compatibility note: Lisp Machine Lisp uses `eq` for the comparison. In Lisp Machine Lisp `case` therefore works for fixnums but not bignums. In the interest of hiding the fixnum-bignum distinction, `case` uses `eql` in Common Lisp.
>
> There is another problem. It is useful to let `( )` as a test mean an empty list,that is, a list of no keys. Such a clause cannot ever be selected. This is mostly useful for macros which want to compute lists of keys, where some lists might turn out to be empty. This is incompatible with Lisp systems in which `( )` is the same as `nil`, because they typically treat `nil` as a symbol and not as an empty list in this context.

For example:

```
(print (case errorcount
         ((0) '(no errors))
         ((1) '(1 error))
         (() '(uncountable errors))          ;Cannot be selected.
         ((fatal die) '(fatal error - aborting))
         (t (list errorcount 'errors))))
```

If there is only one key for a clause, then that key may be written in place of a list of that key,

provided that no ambiguity results (the key should not be a cons or one of `()`, `t`, or `otherwise`).

`typecase` *keyform* {(*type* {*form*}*)}* [*Special form*]

`typecase` is a conditional which chooses one of its clauses by examining the type of an object. Its form is as follows:

```
(typecase keyform
  (type-1 consequent-1-1 consequent-1-2 ...)
  (type-2 consequent-2-1 ...)
  (type-3 consequent-3-1 ...)
  ...)
```

Structurally `typecase` is much like `cond` (page 58) or `case` (page 60), and it behaves like them in selecting one clause and then executing all consequents of that clause. It differs in the mechanism of clause selection.

The first thing `typecase` does is to evaluate the form *keyform* to produce an object called the key object. Then `typecase` considers each of the clauses in turn. The first clause for which the key is of that clause's specified *type* is selected, the consequents of this clause are evaluated as an implicit `progn`, and `typecaseq` returns what was returned by the last consequent (or `()` if there are no consequents in that clause). If no clause is satisfied, `typecase` returns `()`.

As for `case`, the symbol `t` or `otherwise` may be written for *type* to indicate that the clause should always be selected.

It is permissible for more than one clause to specify a given type, particularly if one is a subtype of another; the earliest applicable clause is chosen.

For example:

```
(typecase an-object
   (string ...)                ;This clause handles strings.
   ((array t) ...)             ;This clause handles general arrays.
   ((array bit) ...)           ;This clause handles bit arrays.
   (array ...)                 ;This handles all other arrays.
   (t ...))                    ;This handles all other objects.
```

A COMMON LISP compiler may choose to issue a warning if a clause cannot be selected because it is completely shadowed by earlier clauses.

5.7. Iteration

COMMON LISP provides a number of iteration constructs. The `do` (page 49) and `do*` (page 51) constructs provides a general iteration facility. For simple iterations over lists or *n* consecutive integers, `dolist` (page 52) and related constructs are provided. The `prog` (page 55) construct is the most general, permitting arbitrary `go` (page 57) statements within it. All of the iteration constructs permit statically defined non-local exits in the form of the `return` (page 58) statement and its variants.

declarations

5.7.1. General iteration

`do` ({(*var* [*init* [*step*]])}*) (*end-test* {*form*}*) {*tag* | *statement*}* [*Special form*]

The `do` special form provides a generalized iteration facility, with an arbitrary number of "index variables". These variables are bound within the iteration and stepped in parallel in specified ways. They may be used both to generate successive values of interest (such as successive integers) or to accumulate results. When an end condition is met, the iteration terminates with a specified value.

In general, a `do` loop looks like this:

```
(do ((var1 init1 step1)
     (var2 init2 step2)
     ...
     (varn initn stepn))
    (end-test . result)
  . progbody)
```

The first item in the form is a list of zero or more index-variable specifiers. Each index-variable specifier is a list of the name of a variable *var*, an initial value *init* (which defaults to `()` if it is omitted) and a stepping form *step*. If *step* is omitted, the *var* is not changed by the `do` construct between repetitions (though code within the `do` is free to alter the value of the variable by using `setq` (page 47)).

An index-variable specifier can also be just the name of a variable. In this case, the variable has an initial value of `()`, and is not changed between repetitions.

Before the first iteration, all the *init* forms are evaluated, and then each *var* is bound to the value of its respective *init*. This is a binding, not an assignment; when the loop terminates the old values of those variables will be restored. Note that *all* of the *init* forms are evaluated *before* any *var* is bound; hence *init* forms may refer to old values of the variables.

The second element of the `do`-form is a list of an end-testing predicate form *end-test*, and zero or more forms, called the *result* forms. This resembles a `cond` clause. At the beginning of each iteration, after processing the variables, the *end-test* is evaluated. If the result is `()`, execution proceeds with the body of the `do`. If the result is not `()`, the *result* forms are evaluated in order as an implicit `progn` (page 55), and then `do` returns. `do` returns the results of evaluating the last *result* form. If there are no *result* forms, the value of `do` is `()`; note that this is *not* quite analogous to the treatment of clauses in a `cond` (page 58) special form.

At the beginning of each iteration other than the first, the index variables are updated as follows. First every *step* form is evaluated, from left to right. Then the resulting values are assigned (as with `psetq` (page 48)) to the respective index variables. Any variable which has no associated *step* form is not affected. Because *all* of the *step* forms are evaluated before *any* of the variables are altered, when a step form is evaluated it always has access to the *old* values of the index variables, even if other step forms precede it. After this process, the end-test is evaluated as described above.

If the end-test of a `do` form is `()`, the test will never succeed. Therefore this provides an idiom for

"do forever". The *body* of the `do` is executed repeatedly, stepping variables as usual, of course. The infinite loop can be terminated by the use of `return` (page 58), `return-from` (page 58), `go` (page 57) to an outer level, or `throw` (page 65).

For example:

```
(do ((j 0 (+ j 1)))
    (())                                ;Do forever.
  (format t "~%Input ~D:" j)
  (let ((item (read)))
    (if (null item) (return)            ;Process items until () seen.
        (format t "~&Output ~D: ~S" j (process item)))))
```

The remainder of the `do` form constitutes a `prog` body. The function `return` (page 58) and its variants may be used within a `do` form to terminate it immediately, returning a specified result. Tags may appear within the body of a `do` loop for use by `go` (page 57) statements. When the end of a `do` body is reached, the next iteration cycle (beginning with the evaluation of *step* forms) occurs.

`declare` (page 72) forms may appear at the beginning of a `do` body. They apply to code in the `do` body, to the bindings of the `do` variables, to the *step* forms (but *not* the *init* forms), to the *end-test*, and to the *result* forms.

> Compatibility note: "Old-style" MACLISP do loops, of the form (`do` *var init step end-test . body*), are not supported. They are obsolete, and are easily converted to a new-style `do` with the insertion of three pairs of parentheses. In practice the compiler can catch nearly all instances of old-style `do` loops because they will not have a legal format anyway.

For example:

```
(do ((i 0 (+ i 1))          ;Sets every element of an-array to empty
     (n (array-length an-array)))
    ((= i n))
  (aset 'empty an-array i))
```

The construction

```
(do ((x e (cdr x))
     (oldx x x))
    ((null x))
  body)
```

exploits parallel assignment to index variables. On the first iteration, the value of `oldx` is whatever value `x` had before the `do` was entered. On succeeding iterations, `oldx` contains the value that `x` had on the previous iteration.

~~Very often~~ an iterative algorithm can be most clearly expressed entirely in the *step* forms of a `do`, and the *body* is empty.

For example:

```
(do ((x foo (cdr x))
     (y bar (cdr y))
     (z '() (cons (f (car x) (car y)) z)))
    ((or (null x) (null y))
     (nreverse z)))
```

does the same thing as `(mapcar #'f foo bar)`. Note that the *step* computation for `z` exploits

the fact that variables are stepped in parallel. Also, the body of the loop is empty. Finally, the use of `nreverse` (page 77) to put an accumulated `do` loop result into the correct order is a standard idiom.

Other examples:

```
(defun length (list)
       (do ((x list (cdr x))
            (j 0 (+ j 1)))
           ((atom x) j)))

(defun reverse (list)
       (do ((x list (cdr x))
            (y '() (cons (car x) y)))
           ((atom x) y)))
```

Not used defns now!

Note the use of `atom` rather than `null` to test for the end of a list in the above two examples. This results in more robust code; it will not attempt to cdr the end of a dotted list.

As an example of nested loops, suppose that `env` holds a list of conses. The *car* of each cons is a list of symbols, and the *cdr* of each cons is a list of equal length containing corresponding values. Such a data structure is similar to an association list, but is divided into "frames"; the overall structure resembles a rib-cage. A lookup function on such a data structure might be:

```
(defun ribcage-lookup (sym ribcage)
       (do backbone-loop
           ((r ribcage (cdr r)))
           ((null r) ())
         (do rib-loop
             ((s (caar r) (cdr s))
              (v (cdar r) (cdr v)))
             ((null s))
           (when (eq (car s) sym)
                 (return-from backbone-loop (car v))))))
```

(Notice the use of indentation in the above example to set off the bodies of the `do` loops.)

copy from do

`do*` *bindspecs endtest {form}** [*Function*]

`do*` is exactly like `do` except that the bindings and steppings of the variables are performed sequentially rather than in parallel. At the beginning each variable is bound to the value of its *init* form before the *init* form for the next variable is evaluated. Similarly, between iterations each variable is given the new value computed by its *step* form before the *step* form of the next variable is evaluated.

5.7.2. Simple Iteration Constructs

The constructs `dolist` and `dotimes` perform a body of statements repeatedly. On each iteration a specified variable is bound to an element of interest which the body may examine. `dolist` examines successive elements of a list, and `dotimes` examines integers from *0* to *n-1* for some specified positive integer *n*.

minus

The value of any of these constructs may be specified by an optional result form, which if omitted defaults to the value ( ).

The `return` (page 58) ~~or `return-from` (page 58)~~ statement may be used to return immediately from a `dolist` or `dotimes` form, discarding any following iterations which might have been performed. ~~The loop may be given a name for this purpose by writing it directly before the binding specification.~~ The body of the loop is in fact a `prog` (page 55) body; it may contain tags to serve as the targets of `go` (page 57) statements, and may have `declare` (page 72) forms at the beginning.

`dolist` (*var listform* [*resultform*]) {*tag* | *statement*}* [*Special form*]

`dolist` provides straightforward iteration over the elements of a list. The expression (`dolist` (*var listform resultform*) . *progbody*) evaluates the form *listform*, which should produce a list. It then performs *progbody* once for each element in the list, in order, with the variable *var* bound to the element. Then *resultform* (a single form, *not* an implicit `progn`) is evaluated, and the result is the value of the `dolist` form. If *resultform* is omitted, the result is ( ).

For example:

```
(dolist (x '(a b c d)) (prin1 x) (princ " ")) => ()
   after printing "a b c d "
```

The loop may be named by placing the name before the binding specification. An explicit `return` statement may be used to terminate the loop and return a specified value.

Compatibility note: The *resultform* part of a `dolist` is not currently supported in Lisp Machine Lisp. It seems to improve the utility of the construct markedly.

`dotimes` (*var countform* [*resultform*]) {*tag* | *statement*}* [*Special form*]

`dotimes` provides straightforward iteration over a sequence of integers. The expression (`dotimes` (*var countform resultform*) *progbody*) evaluates the form *countform*, which should produce an integer. It then performs *progbody* once for each integer from zero (inclusive) to *count* (exclusive), in order, with the variable *var* bound to the integer; if the integer is zero or negative, then the *progbody* is performed zero times. Finally, *resultform* (a single form, *not* an implicit `progn`) is evaluated, and the result is the value of the `dotimes` form. If *resultform* is omitted, the result is ( ).

Altering the value of *var* in the body of the loop (by using `setq` (page 47), for example) will have unpredictable, possibly implementation-dependent results. A COMMON LISP compiler may choose to issue a warning if such a variable appears in a `setq`.

For example:

```
(defun string-posq (char string &optional
                    (start 0)
                    (end (string-length string)))
       (dotimes (k (- end start) '())
                (when (char= char (char string (+ start k)))
                      (return k))))
```

The loop may be named by placing the name before the binding specification. An explicit `return`

statement may be used to terminate the loop and return a specified value.

5.7.3. Mapping

Mapping is a type of iteration in which a function is successively applied to pieces of one or more sequences. The result of the iteration is a sequence containing the respective results of the function applications. There are several options for the way in which the pieces of the list are chosen and for what is done with the results returned by the applications of the function.

In COMMON LISP mapping is done by two kinds of constructs: mapping functions and `for`-loops. Mapping functions take functional arguments and apply them as described above. `for`-loops are special forms which are often syntactically more convenient; they have bodies, which can refer to a bound variable, and the value of the body provides a result.

`mapcar` *function list* `&rest` *more-lists* [*Function*]
`maplist` *function list* `&rest` *more-lists* [*Function*]
`mapc` *function list* `&rest` *more-lists* [*Function*]
`mapl` *function list* `&rest` *more-lists* [*Function*]
`mapcan` *function list* `&rest` *more-lists* [*Function*]
`mapcon` *function list* `&rest` *more-lists* [*Function*]

For each these mapping functions, the first argument is a function and the rest must be lists. The function must take as many arguments as there are lists.

`mapcar` operates on successive elements of the lists. First the function is applied to the *car* of each list, then to the *cadr* of each list, and so on. (Ideally all the lists are the same length; if not, the iteration terminates when the shortest list runs out, and excess elements in other lists are ignored.) The value returned by `mapcar` is a list of the results of the successive calls to the function.

For example:

```
(mapcar #'abs '(3 -4 2 -5 -6)) => (3 4 2 5 6)
(mapcar #'cons '(a b c) '(1 2 3)) => ((a . 1) (b . 2) (c . 3))
```

~~Often `for` is better (page FORLISTS-FUN) is more convenient to use than `mapcar`.~~

`maplist` is like `mapcar` except that the function is applied to the list and successive cdr's of that list rather than to successive elements of the list.

For example:

```
(maplist #'(lambda (x) (cons 'foo x))
         '(a b c d))
   => ((foo a b c d) (foo b c d) (foo c d) (foo d))
(maplist #'(lambda (x) (if (member (car x) (cdr x)) 0 1)))
         '(a b a c d b c))
   => (0 0 1 0 1 1 1)
   ; An entry is 1 iff the corresponding element of the input
   ;    list was the last instance of that element in the input list.
```

`mapl` and `mapc` are like `maplist` and `mapcar` respectively, except that they do not accumulate

the results of calling the function.

> **Compatibility note:** In all LISP systems since LISP 1.5, `mapl` has been called `map`. In the chapter on sequences it is explained why this was a bad choice. Here the name `map` is used for the far more useful generic sequence mapper, in closer accordance to the computer science literature, especially the growing body of papers on functional programming.

These functions are used when the function is being called merely for its side-effects, rather than its returned values. The value returned by `mapl` or `mapc` is the second argument, that is, the first sequence argument.

`mapcan` and `mapcon` are like `mapcar` and `maplist` respectively, except that they combine the results of the function using `nconc` (page 92) instead of `list`. That is,

```
(mapcon f x1 ... xn)
   <=> (apply #'nconc (maplist f x1 ... xn))
```

and similarly for the relationship between `mapcan` and `mapcar`. Conceptually, these functions allow the mapped function to return a variable number of items to be put into the output list. This is particularly useful for effectively returning zero or one item:

```
(mapcan #'(lambda (x) (and (numberp x) (list x)))
        '(a 1 b c 3 4 d 5))
   => (1 3 4 5)
```

In this case the function serves as a filter; this is a standard LISP idiom using `mapcan`. (The function ~~`remove-if-not`~~ (page 79) might have been useful in this particular context, however.) Remember that `nconc` is a destructive operation, and therefore so are `mapcan` and `mapcon`; the lists returned by the *function* are altered in order to concatenate them.

Sometimes a `do` or a straightforward recursion is preferable to a mapping operation; however, the mapping functions should be used wherever they naturally apply because this increases the clarity of the code.

The functional argument to a mapping function must be acceptable to `apply`; it cannot be a macro or the name of a special form. Of course, there is nothing wrong with using functions which have `&optional` and `&rest` parameters.

There are also functions (`mapatoms` (page MAPATOMS-FUN) and `mapatoms-all` (page MAPATOMS-ALL-FUN)) for mapping over all symbols in certain packages.

5.7.4. The Program Feature

LISP implementations since LISP 1.5 have had what was originally called "the program feature", as if it were impossible to write programs without it! The `prog` construct allows one to write in an ALGOL-like or FORTRAN-like statement-oriented style, using `go` statements which can refer to tags in the body of the `prog`. Contemporary LISP programming style tends to use `prog` rather infrequently. The various iteration constructs, such as `do` (page 62), have bodies with the characteristics of a `prog`.

`prog` ({*var* | (*var* *init*)}*) {*tag* | *statement*}* [*Special form*]

`prog` is a special form which provides bound temporary variables, sequential evaluation of forms, and a "goto/return" facility. It is this latter characteristic which distinguishes `prog` from other LISP constructs; `lambda` (page LAMBDA-FUN) and `let` (page 56) also provide local variable bindings, and `progn` (page 55) also evaluates forms sequentially.

A typical `prog` looks like:

```
(prog (var1 var2 (var3 init3) var4 (var5 init5))
      statement1
 tag1
      statement2
      statement3
      statement4
 tag2
      statement5
      ...
      )
```

The list after the keyword `prog` is a set of specifications for binding *var1*, *var2*, etc., which are temporary variables, bound locally to the `prog`. This list is processed exactly as the list in a `let` (page 56) statement: first all the *init* forms are evaluated from left to right (where `()` is used for any omitted *init* form), and then the variables are all bound in parallel to the respective results. (`prog*` (page 57) is the same as `prog` except that this initialization is sequential rather than parallel.)

The part of a `prog` after the variable list is called the *body*. An item in the body may be a symbol or a number, in which case it is called a *tag*, or any other COMMON LISP form, in which case it is called a *statement*.

After `prog` binds the temporary variables, it processes each form in its body sequentially. *tags* are ignored; *statements* are evaluated, and their returned values discarded. If the end of the body is reached, the `prog` returns `()`. However, two special forms may be used in `prog` bodies to alter the flow of control. If (`return` *x*) is evaluated, `prog` stops processing its body, evaluates *x*, and returns the result. If (`go` *tag*) is evaluated, `prog` jumps to the part of the body labelled with the *tag* (that is, with an atom `eql` (page 39) to *tag*). *tag* is not evaluated.

Compatibility note: The "computed `go`" feature of MACLISP is not supported. The syntax of a computed `go` is idiosyncratic, and the feature is not supported by Lisp Machine LISP, NIL, or INTERLISP.

`go` and `return` forms must be *lexically* within the scope of the `prog`; it is not possible for one function to `return` to a `prog` which is in progress in its caller. Thus, a program which contains a `go` which is not contained within the body of a `prog` (or other constructs such as `do`, which have `prog` bodies) are in error. A dynamically scoped non-local exit mechanism is provided by `catch` (page 63) and `throw` (page 65) and other related operations.

Sometimes code which is lexically within more than one `prog` form needs to `return` from one of the outer `prog`s. However, the `return` function normally returns from the innermost `prog`.

Here is a fine example of what can be done with `prog`:

```
(defun king-of-confusion (w)
       (prog (x y z)     ;Initialize x, y, z to ()
             (setq y (car w) z (cdr w))
        loop
             (cond ((null y) (return x))
                   ((null z) (go err)))
        rejoin
             (setq x (cons (cons (car y) (car z)) x))
             (setq y (cdr y) z (cdr z))
             (go loop)
        err
             (error "Mismatch - gleep!")
             (setq z y)
             (go rejoin))
```

which is accomplished somewhat more perspicuously by:

```
(defun prince-of-clarity (w)
       (do ((y (car w) (cdr y))
            (z (cdr w) (cdr z))
            (x '() (cons (cons (car y) (car z)) x)))
           ((null y) x)
         (when (null z)
               (error "Mismatch - gleep!")
               (setq z y))))
```

Declarations may appear at the beginning of a `prog` body; see `declare` (page 72).

`prog*` copy from prog [*Special form*]

The `prog*` special form is almost the same as `prog`. The only difference is that the binding and initialization of the temporary variables is done *sequentially*, so that the *init* form for each one can use the values of previous ones. Therefore `prog*` is to `prog` as `let*` (page 57) is to `let` (page 56).

For example:

```
(prog* ((y z) (x (car y)))
       (return x))
```

returns the car of the value of `z`.

`go` *tag* [*Special form*]

The `(go` *tag*`)` special form is used to do a "go to" within a a `prog` body. The *tag* must be a symbol or a number; *tag* is not evaluated. `go` transfers control to the point in the body labelled by a tag `equal` to the one given. If there is no such tag in the body, the bodies of lexically containing `prog` bodies (if any) are examined as well. It is an error if there is no matching tag.

The `go` form does not ever return a value. A `go` form may not appear as an argument to an ordinary function, but only at the top level of a `prog` body or within certain special forms such as conditionals which are within a `prog` body.

For example:

```
(prog ((n (string-length a-string)) (j 0))
 loop (when (= j n) (return a-string))
      (when (char= #\Space (char j a-string))
            (return (substring a-string 0 j)))
      (increment j)
      (go loop))
```

returns the first "word" in `a-string`, where words are separated by spaces. This could of course have been expressed more succinctly as:

```
(dotimes (j (string-length a-string) a-string)
   (when (char= #\Space (char j a-string))
         (return (substring a-string 0 j))))
```

As a matter of style, it is recommended that the user think twice before using a `go`. Most purposes of `go` can be accomplished with one of the iteration primitives, nested conditional forms, or `return-from` (page 58). If the use of `go` seems to be unavoidable, perhaps the control structure implemented by `go` should be packaged up as a macro definition. (If the use of `go` is avoidable, and `return` also is not needed, then `prog` probably is not needed either; `let` can be used to bind variables and then execute some statements.)

`return` *result* [*Special form*]

`return` is used to return from a `prog`, `do`, or similar iteration construct. Whatever the evaluation of *result* produces is returned by the construct being exited by `return`.

```
(defun member (item list)
       (do ((x list (cdr x)))
           ((null x) '())
         (when (equal item (car x))
               (return x))))
```

`return` is, like `go`, a special form which does not return a value. Instead, it causes a containing iteration construct to return a value. If the evaluation of *result* produces multiple values, those multiple values are returned by the construct exited.

If the symbol `t` is used as the name of a `prog`, then it will be made "invisible" to `return` forms; any `return` inside that `prog` will return to the next outermost level whose name is not `t`. `(return-from t ...)` will return from a `prog` named `t`. This feature is not intended to be used by user-written code; it is for macros to expand into.

`return-from` *progname result* [*Special form*]

This is just like `return`, except that before the *result* form is written a symbol (not evaluated), which is the name of the construct from which to return. See the descriptions of the special forms `do` (page 62) and `prog` (page 68) for examples.

5.8. Multiple Values

Ordinarily the result of calling a LISP function is a single LISP object. Sometimes, however, it is convenient for a function to compute several quantities and return them. COMMON LISP provides a mechanism for handling multiple values directly. This mechanism is cleaner and more efficient than the usual tricks involving returning a list of results or stashing results in global variables.

5.8.1. Constructs for Handling Multiple Values

Normally multiple values are not used. Special forms are required both to *produce* multiple values and to *receive* them. If the caller of a function does not request multiple values, but the called function produces multiple values, then the first value is given to the caller and all others are discarded (and if the called function produces zero values then the caller gets ( ) as a value).

The primary primitive for producing multiple values is `values` (page 59), which takes any number of arguments and returns that many values. If the last form in the body of a function is a `values` with three arguments, then a call to that function will return three values. Other special forms also produce multiple values, but they can be described in terms of `values`. Some built-in COMMON LISP functions (such as `floor` (page 128)) return multiple values; those which do are so documented.

The special forms for receiving multiple values are `multiple-value-setq` (page MULTIPLE-VALUE-SETQ-FUN), `multiple-value-let` (page MULTIPLE-VALUE-LET-FUN), `multiple-value-list` (page 60), and `multiple-value-vector` (page 60). These specify a form to evaluate and an indication of where to put the values returned by that form.

`values &rest` *args* [*Function*]

Returns all of its arguments, in order, as values.

For example:

```
(defun polar (x y)
      (values (sqrt (+ (* x x) (* y y))) (atan y x)))
(multiple-value-let (r theta) (polar 3.0 4.0)
     (list r theta))
  => (5.0 0.9272952)
```

The expression `(values)` returns zero values.

`values-list` *list* [*Function*]

Returns as multiple values all the elements of *list*.

For example:

```
(values-list (list a b c)) <=> (values a b c)
```

`multiple-value-list` *form* [*Special form*]
`multiple-value-vector` *form* [*Special form*]

`multiple-value-list` evaluates *form*, and returns a list of the multiple values it returned. `multiple-value-vector` is similar, but returns a general vector containing the multiple values.

For example:

```
(multiple-value-list (floor -3 4)) => (-1 1)
(multiple-value-vector (floor -3 4)) => #(-1 1)
```

`mvcall` *function* {*form*}* [*Special form*]

`mvcall` first evaluates *function* to obtain a function, and then evaluates all of the *forms*. All the the values of the *forms* are gathered together (not just one value from each), and given as arguments to the function. The result of `mvcall` is whatever is returned by the function.

For example:

```
(mvcall #'+ (floor 5 3) (floor 7 3)) <=> (+ 1 2 2 1) => 6
(multiple-value-list form) <=> (mvcall #'list form)
```

`mvprog1` *form* {*form*}* [*Special form*]

`mvprog1` evaluates the first *form* and saves all the values produced by that form. It then evaluates the other *forms* from left to right, discarding their values. The values produced by the first *form* are returned by `mvprog1`. See `prog1` (page 55), which always returns a single value.

`mvlet` *lambda-list values-form* {*form*}* [*Special form*]

`mvlet` evaluates *values-form*, possibly obtaining multiple values, and binds the variables specified in *lambda-list* to these values while the forms in *body* (an implicit `progn`) are evaluated. Whatever is returned by the last form of *body* is returned by `mvlet`.

(`mvlet` *bindings form* . *body*)

does exactly the same thing as

(`apply #'(lambda` *bindings* . *body*) (`multiple-value-list` *form*))

but using `mvlet` is potentially much more efficient.

`mvsetq` *lambda-list form* [*Special form*]

This special form causes the variables in *lambda-list* to get as values the multiple values returned from the evaluation of *form*; the assignment to the variables is as with `setq` (page 47).

The *lambda-list* is allowed to have the full syntax of the binding specifications for a `lambda` expression, including `&optional` and `&rest` keywords. However, this construct performs *assignment* rather than *binding*.

The result of a `mvsetq` form is a single value, the first one returned by *form*, or () if *form* returns zero values.

`multiple-value-bind` .({*var*}*) *values-form* {*form*}* [*Special form*]

The *values-form* is evaluated, and each of the variables *var* is bound to the respective value returned by that form. If there are more variables than values returned, extra values of ( ) are given to the remaining variables. If there are more values than variables, the excess values are simply discarded. The variables are bound to the values over the execution of the forms, which make up an implicit `progn`.

Compatibility note: This is compatible with Lisp Machine LISP.

For example:

```
(multiple-value-bind (x) (floor 5 3) (list x)) => (1)
(multiple-value-bind (x y) (floor 5 3) (list x y)) => (1 2)
(multiple-value-bind (x y z) (floor 5 3) (list x y z))
   => (1 2 ())
```

In general,

```
(multiple-value-bind (x y z ...) form . body)
   <=>
(mvlet (&optional (x ()) (y ()) (z ()) &rest ())
  form . body)
```

`multiple-value` *variables form* [*Special form*]

The *variables* must be a list of variables. The *form* is evaluated, and the variables are *set* (not bound) to the values returned by that form. If there are more variables than values returned, extra values of ( ) are assigned to the remaining variables. If there are more values than variables, the excess values are simply discarded.

Compatibility note: This is compatible with Lisp Machine LISP.

`multiple-value` always returns a single value, which is the first value returned by *form*, or ( ) if *form* produces zero values.

5.8.2. Rules for Tail-Recursive Situations

It is often the case that the value of a special form is defined to be the value of one of its sub-forms. For example, the value of a `cond` is the value of the last form in the selected clause. In most such cases, if the sub-form produces multiple values, the original form will also produce all of those values. This *passing-back* of multiple values of course has no effect unless eventually one of the special forms for receiving multiple values is reached.

To be explicit, multiple values can result from a special form under precisely these circumstances:

- `eval` (page EVAL-FUN) returns multiple values if the form given it to evaluate produces multiple values.
- `apply` (page 54), `funcall` (page 54), `funcall*` (page 55), `mvcall` (page 72), `subrcall` (page SUBRCALL-FUN), and `subrcall*` (page SUBRCALL*-FUN) pass back multiple values from the function applied or called.

- When a `lambda` (page LAMBDA-FUN)-expression is invoked, the function passes back multiple values from the last form of the `lambda` body (which is an implicit `progn`).

- Indeed, `progn` (page 55) itself passes back multiple values from its last form, as does any construct some part of which is defined to be an "implicit `progn`"; these include `progv` (page 58), `let` (page 56), `let*` (page 57),`when` (page 59), `unless` (page 60), `case` (page 60), `typecase` (page 61), `mvlet` (page 72), `mvsetq` (page 72), `multiple-value-bind` (page 73), `multiple-value` (page 73), `catch` (page 63), and `catch-all` (page 63).

- `mvprog1` (page 72) passes back multiple values from its first form. However, `prog1` (page 55) always returns a single value.

- `unwind-protect` (page 64) returns multiple values if the form it protects does.

- `catch` (page 63) returns multiple values if the result form in a `throw` (page 65) exiting from such a catch produces multiple values.

- `cond` (page 58) passes back multiple values from the last form of the implicit `progn` of the selected clause. If, however, the clause selected is a singleton clause, then only a single value (the non-`()` predicate value) is returned. This is true even if the singleton clause is the last clause of the `cond`. It is *not* permitted to treat a final clause "`(x)`" as being the same as "`(t x)`" for this reason; the latter passes back multiple values from the form `x`.

- `if` (page 59) passes back multiple values from whichever form is selected (the *then* form or the *else* form).

- `and` (page 42) and `or` (page 42) pass back multiple values from the last form, but not from forms other than the last.

- `do` (page 62), `prog` (page 68), `prog*` (page 69), and other constructs from which `return` (page 70) can return, each pass back the multiple values of the form appearing in In addition, `do` passes back multiple values from the last form of the exit clause, exactly as if the exit clause were a `cond` clause.

Among special forms which *never* pass back multiple values are `setq` (page 47), `multiple-value` (page 73), and `prog1` (page 55). A good way to force only one value to be returned from a form `x` is to write `(values x)`.

The most important rule about multiple values, however, is:

No matter how many values a form produces,
if the form is an argument form in a function call,
then exactly ONE value (the first one) is used.

For example, if you write `(cons (foo x))`, then `cons` will receive *exactly* one argument, even if `foo` returns two values. Each argument form produces exactly one argument. If such a form returns zero values, `()` is used for the argument. Similarly, conditional constructs which test the value of a form will use exactly one value (the first) from that form and discard the rest, or use `()` if zero values are returned.

rationale

5.9. Dynamic Non-local Exits

COMMON LISP provides a facility for exiting from a complex process in a non-local, dynamically scoped manner. There are two classes of special forms for this purpose, called *catch* forms and *throw* forms, or simply *catches* and *throws*. A catch form evaluates some subforms in such a way that, if a throw form is executed during such evaluation, the evaluation is aborted at that point and the catch form immediately returns a value specified by the throw. Unlike `block` (page BLOCK-FUN) and `return` (page 70), which allow for so exiting a `block` form from any point lexically within the body of the `block`, the catch/throw mechanism works even if the throw form is not textually within the body of the catch form. The throw need only occur within the extent (time span) of the evaluation of the body of the catch. This is analogous to the distinction between dynamically bound (special) variables and lexically bound (local) variables.

5.9.1. Catch Forms

`catch` *tag* {*form*}* [*Special form*]

The `catch` special form is the simplest catcher. The *tag* is evaluated first to produce an object that names the catch; it may be any LISP object. The *forms* are evaluated as an implicit `progn`, and the results of the last form are returned, except that if during the evaluation of the *forms* a throw should be executed, such that the *tag* of the throw matches (is `eq` to) the *tag* of the `catch`, then the evaluation of the *forms* is aborted and the results specified by the throw are immediately returned from the `catch` expression.

The tag is used to match up throws with catches (using `eq`, not `eql`; therefore numbers should not be used as catch tags). (`catch 'foo` *form*) will catch a (`throw 'foo` *form*) but not a (`throw 'bar` *form*). It is an error if `throw` is done when there is no suitable `catch` (or one of its variants) ready to catch it.

Compatibility note: This syntax for `catch` is not compatible with MACLISP. Lisp Machine LISP defines `catch` to be compatible with that of MACLISP, but discourages its use. The definition here is compatible with ().

Lisp Machine LISP defines `*catch` to return four values. This is complicated, implementation-dependent, and not terribly useful. Here we simply define `catch` to be consistent with the standard convention on the interaction of multiple values with implicit `progn` forms, and with a throw "tail-recursing" out of the matching catch, by analogy with `return` and `prog`.

`catch-all` *catch-function* {*form*}* [*Special form*]
`unwind-all` *catch-function* {*form*}* [*Special form*]

`catchall` behaves roughly like `catch`, except that instead of a *tag*, a *catch-function* is provided. If no throw occurs during the evaluation of the *forms*, then this behaves just as for `catch`: the `catchall` form returns what is returned from evaluation of the last of the *forms*. `catch-all` will catch *any* throw not caught by some inner catcher, however; if such a throw occurs, then the function is called, and whatever it returns is returned by `catch-all`. The *catch-function* will get one or more arguments; the first argument is always the throw tag, and the other arguments are the thrown results (there may be more than one if the *result* form for the throw produces multiple values).

The `catch-all` is not in force during execution of the *catch-function*. If a throw occurs within the *catch-function*, it will throw to some catch exterior to the `catch-all`. This is useful because the *catch-function* can examine the tag, and if it is not of interest can relay the throw.

```
(catch-all #'(lambda (tag &rest results)
               (caseq tag                          ;Check tag.
                 (win (values-list results))       ;If win, return results.
                 (lose (cleanup)                   ;If lose, clean up
                       (ferror "Lose lose!"))      ;  and signal an error.
                 (otherwise                        ;Otherwise relay throw.
                  (throw tag (values-list results)))))
             (determine-win-or-lose))
```

`unwind-all` is just like `catch-all` except that the *catch-function* is always called, even if no throw occurs; in that case the first argument (the "tag") to the *catch-function* is ( ), and the other arguments are the results from the last of the *forms*. Often `unwind-protect` is more suitable for a given task than `unwind-all`, however; the choice should be weighed for any particular application.

`unwind-protect` *protected-form* {*cleanup-form*}* [*Special form*]

Sometimes it is necessary to evaluate a form and make sure that certain side-effects take place after the form is evaluated; a typical example is:

```
(progn (start-motor)
       (drill-hole)
       (stop-motor))
```

The non-local exit facility of Lisp creates a situation in which the above code won't work, however: if `drill-hole` should do a throw to a catch which is outside of the `progn` form (perhaps because the drill bit broke), then `(stop-motor)` will never be evaluated (and the motor will presumably be left running). This is particularly likely if `drill-hole` causes a LISP error and the user tells the error-handler to give up and abort the computation. (A possibly more practical example might be:

```
(prog2 (open-a-file)
       (process-file)
       (close-the-file))
```

where it is desired always to close the file when the computation is terminated for whatever reason.)

In order to allow the above program to work, it can be rewritten using `unwind-protect` as follows:

```
(unwind-protect
  (progn (turn-on-water-start-motor)
         (drill-hole))
  (stop-motor))
```

If `drill-hole` does a throw which attempts to quit out of the `unwind-protect`, then `(stop-motor)` will be executed.

As a general rule, `unwind-protect` guarantees to execute all the *cleanup-forms* before exiting, whether it terminates normally or is aborted by a throw of some kind. `unwind-protect` returns

whatever results from evaluation of the *protected-form*, and discards all the results from the *cleanup-forms*.

5.9.2. Throw Forms

`throw` *tag result* [*Special form*]

The `throw` special form is the simplest thrower. The *tag* is evaluated first to produce an object called the throw tag. The most recent outstanding catch whose tag matches the throw tag is exited. Some catches, such as a `catch-all`, will match any throw tag; a `catch` matches only if the catch tag is `eq` to the throw tag.

In the process dynamic variable bindings are undone back to the point of the catch, and any intervening `unwind-protect` cleanup code is executed. The *result* form is evaluated before the unwinding process commences, and whatever results it produces are returned from the catch (or given to the *catch-function*, if appropriate).

If there is no outstanding catch whose tag matches the throw tag, no unwinding of the stack is performed, and an error is signalled. When the error is signalled, the outstanding catches and the dynamic variable bindings are those in force at the point of the throw.

Implementation note: These requirements imply that throwing must be done by two passes over the control stack. In the first pass one simply searches for a matching catch. In this search every `catch`, `catch-all`, and `unwind-all` must be considered, but every `unwind-protect` should be ignored. On the second pass the stack is actually unwound, one frame at a time, undoing dynamic bindings and outstanding `unwind-protect`s in reverse order of creation until the matching catch is reached.

3

Accually, one pass suffi.

Chapter 6

FUNC

Chapter 7

MACRO

Chapter 8
Declarations

Examples. Point to DEFVAR & DEFCONST.

Declarations allow you to specify extra information about your program to the LISP system. All declarations are completely optional and do not affect the meaning of a correct program, with one exception: `special` declarations do affect the interpretation of variable bindings and references, and so must be specified where appropriate. All other declarations are of an advisory nature, and may be used by the LISP system to aid you by performing extra error checking or producing more efficient compiled code. Declarations are also a good way to add documentation to a program.

Compatibility note: DECLARE forms are not evaluated! See EVAL-WHEN. In both interp & compiler

8.1. Declaration Syntax

`declare` {*declaration*}* [*Special form*]

This form may occur only at top level, or at the beginning of the bodies of certain special forms; that is, a `declare` form not at top level may occur only as a statement of such a form, and all statements preceding it (if any) must also be `declare` forms. If a declaration is found anywhere else an error will be signalled.

Each *declaration* form is a list whose *car* is a keyword specifying the kind of declaration it is. Declarations may be divided into two classes: those that concern the bindings of variables, and those that do not. Those which concern variable bindings apply only to the bindings made by the special form at the head of whose body they appear; if such a declaration appears at top level, it applies to the dynamic value of the variable. For example, in

```
(defun foo (x) (declare (type float x)) ... (let ((x 'a)) ...)
```

the type declaration applies only to the outer binding of `x`, and not to the binding made in the `let`.

Compatibility note: This is different from MACLISP, in which type declarations are pervasive.

The top-level declaration

```
(declare (type float tolerance))
```

specifies that the dynamic value of `tolerance` should always be a floating-point number.

Declarations that do not concern themselves with variable bindings are pervasive, affecting all code in the body of the special form (but not code in any initialization forms used to compute initial values for bound variables).

For example:

```
(defun foo (x y) (declare (notinline floor)) ...)
```

advises that everywhere within the body of `foo` the function `floor` should not be open-coded, but called as an out-of-line subroutine. Any pervasive declaration made at top level constitutes a universal declaration, always in force unless locally shadowed.

For example:

```
(declare (inline floor))
```

advises that `floor` should normally be open-coded in-line by the compiler (but within `foo` it will be compiled out-of-line anyway, because of the shadowing local declaration to that effect).

For example:

```
(defun (k x)
  (declare (type integer k))
  (let ((j (foo k x))
        (x (* k k)))
    (declare (inline foo) (special x))
    (foo x j)))
```

In this rather nonsensical example, `k` is declared to be of type `integer`. The `inline` declaration applies to the inner call to `foo`, but not to the one to whose value `j` is bound, because that is *code* in the binding part of the `let`. The `special` declaration of `x` causes the `let` form to make a special binding for `x`, and causes the reference to `x` in the body of the `let` to be a special reference. However, the reference to `x` in the first call to `foo` is a local reference, not a special one.

`locally` {*declare-form*}* {*form*}* [*Special form*]

This special form may be used to make local pervasive declarations where desired. It does not bind any variables, and so cannot be used meaningfully for declarations of variable bindings.

For example:

```
(locally (declare (inline floor))
         (declare (notinline car cdr))
  (floor (car x) (cdr y)))
```

8.2. Declaration Forms

Here is a list of valid declaration forms for use in `declare`. A construct is said to be "affected" by a declaration if it occurs within the scope of a declaration.

`special` `(special` *var1 var2 ...*`)` declares that all of the variables named are to be considered *special*. All variable bindings affected are made to be dynamic bindings, and affected variable references refer to the current dynamic binding rather than the current local binding. (Notice that inner bindings of a variable implicitly shadow a `special` declaration; inner bindings must be explicitly re-declared to be special.)

`type` `(type` *type var1 var2 ...*`)` affects only variable bindings, and declares that the specified variables will take on values only of the specified type.

@RandomKeyword[*type*] (*type var1 var2 ...*) is an abbreviation for (`type` *type var1 var2 ...*) provided that *type* is one of the following symbols:

`null`	`cons`	`list`	`symbol`
`vector`	`string`	`bit-string`	`array`
`function`	`structure`	`random`	`character`
`number`	`stream`	`float`	`string-char`
`integer`	`fixnum`	`bignum`	`bit`
`short-float`	`single-float`	`double-float`	`long-float`
`complex`	`ratio`	`readtable`	`package`
`sequence`			

@Keyword[ftype] (`ftype` *type function1 function2 ...*) declares that the specified functions will be of the functional type *type*.

For example:

```
(declare (ftype (function (integer list) t) nth)
         (ftype (function (number) float) sin cos))
```

@Keyword[function] (`function` *name arglist result-type1 result-type2 ...*) is entirely equivalent to

(`ftype (function` *name arglist result-type1 result-type2 ...*) *name*)

but may be more convenient for some purposes.

For example:

```
(declare (function nth (integer list) t)
         (function sin (number) float)
         (function cos (number) float))
```

@Keyword[inline] (`inline` *function1 function2 ...*) declares that it is desirable for the compiler to open-code calls to the specified functions; that is, the code for a specified function should be integrated into the calling routine, appearing "in line", rather than a procedure call appearing there. This may achieve extra speed at the expense of debuggability (calls to functions compiled in-line cannot be traced, for example). Remember that a compiler is free to ignore this declaration.

@Keyword[notinline] (`notinline` *function1 function2 ...*) declares that it is *undesirable* to compile the specified functions in-line. Remember that a compiler is free to ignore this declaration.

@Keyword[ignore] (ignore *var1 var2 ... varn*) declares that the bindings of the specified variables are never used. It is desirable for a compiler to issue a warning if a variable so declared is ever referred to or is also declared special, or if a variable is lexical, never referred to, and not declared to be ignored.

> ??? Query: This is a new idea: what do people think? This is more mnemonic than writing `ignore` or `()` for an ignored parameter because you can give a meaningful (and possibly conventional) name. It is more explicit and robust than simply mentioning the variable at the front of the lambda-body; the latter convention prevents the compiler from issuing a warning about a possibly malformed program.

@Keyword[optimize] (`optimize` *quality1 quality2 ...*) advises the compiler that *quality1* should be given greatest attention in producing compiled code, then *quality2*, and so on. The qualities may include `speed` (of the compiled code), `space` (both code size and run-time space), and `safety` (run-time error checking); any qualities not mentioned are assumed to be of lower priority than those mentioned. The

default situation is implementation-dependent, but implementors are encouraged to consider `(optimize safety speed space)` for the default.

For example:

```
(defun often-used-subroutine (x y)
  (error-check x y)
  (hairy-setup x)
  (locally
     ;; This inner loop really needs to burn.
     (declare (optimize speed))
     (do ((i 0 (+ i 1))
          (z x (cdr z)))
         ((null z))
       (declare (fixnum i)))))
```

??? Query: This is a new idea: what do people think?

An implementation is free to support other (implementation-dependent) declarations as well. On the other hand, a COMMON LISP compiler is free to ignore entire classes of declarations (for example, implementation-dependent declarations not supported by that compiler's implementation!). Compiler implementors are encouraged, however, to program the compiler by default to issue a warning if the compiler finds a declaration of a kind it never uses (as a hedge against spelling errors).

Chapter 9

Sequences (Cross-Product Version)

This chapter is one of several parallel chapters on sequences. The assumption is that one will be chosen to define the official set of COMMON LISP sequence functions. Reviewers of this draft are encouraged to compare these parallel chapters carefully.

The type `sequence` encompasses objects of type `list`, and one-dimensional arrays (all one-dimensional arrays, not just vectors). While these all are different data structures with different structural properties leading to different algorithmic uses, they do have a common property: each contains contain an ordered set of elements.

There are many operations which are useful on both lists and one-dimensional arrays because they deal with ordered sets of elements. One may ask the number of elements, reverse the ordering, concatenate two ordered sets to form a larger one, and so on. A set of operations are provided on sequences; these are generic operations, which may be applied to lists, vectors, or arrays:

`elt`	`reverse`	`map`	`remove`
`setelt`	`nreverse`	`some`	`position`
`subseq`	`concat`	`every`	`scan-over`
`copyseq`	`reduce`	`notany`	`count`
`length`	`left-reduce`	`notevery`	`mismatch`
`fill`	`right-reduce`	`merge`	`maxprefix`
`replace`	`sort`	`nmerge`	`maxsuffix`
			`search`

The operations in the last column involve search or comparison. Each of these comes in several varieties and two directions. The variety indicates how elements are to be compared; the direction can be either forward or reverse. For example, the `remove` operation has these ten variations:

Forward direction		Reverse direction
`remove`	`remove-from-end`	Compare elements using `equal`
`remq`	`remq-from-end`	Compare elements using `eq`
`rem`	`rem-from-end`	Compare elements with user predicate
`rem-if`	`rem-from-end-if`	Test elements with user predicate
`rem-if-not`	`rem-from-end-if-not`	Test elements with inverse user predicate

Rationale: All of these options multiplied out makes for a very large number of functions: This was deemed more perspicuous than passing flags to a smaller number of functions, and more consistent than providing an incomplete set. `rem-from-end-if-not` seems to be a conceptually atomic operation, for example, despite the fact that its name is made from three separate components.

Compatibility note: In a few of its string functions, Lisp Machine LISP uses the term `-reverse-` in function names to

indicate that the string is traversed in the backwards direction. Unfortunately, there is a possible confusion with the reversing of the string, which is not quite the same thing. NIL has proposed that the letter b be used, presumably standing for "backwards". Here the suffix `-from-end` is proposed; I believe the meaning of this to be more immediately evident.

`elt` *sequence index* [*Function*]

This returns the element of *sequence* specified by *index*, which must be a non-negative integer less than the length of the *sequence*. The first element of any sequence has index `0`.

`setelt` *sequence index newvalue* [*Function*]

The object *newvalue* is stored into the component of the *sequence* specified by *index*, which must be a non-negative integer less than the length of the *sequence*. The first element of any sequence has index `0`. If *sequence* is a specialized array, then the *newvalue* must be an object that the array can contain.

`subseq` *sequence start* `&optional` *end*. [*Function*]

This returns a subsequence of *sequence*, starting at the element specified by the integer index *start* and going up to, but not including, the element specified by the integer index *end*. The length of the subsequence is therefore *end* minus *start*. If *end* is not specified, it defaults to the length of the *sequence*, meaning that all elements after *start* are included. It is an error if *end* is less than *start*, or if either is less than zero or greater than the length of the string.

`subseq` *always* allocates a new sequence for a result; it never shares storage with an old sequence. The result subsequence is always of the same type as the argument *sequence*.

`copyseq` *sequence* [*Function*]

A copy is made of the argument *sequence*; the result is `equal` to the argument but not `eq` to it.

```
(copyseq x) <=> (subseq x 0)
```

but the name `copyseq` is more perspicuous when applicable.

`length` *sequence* [*Function*]

The number of elements in *sequence* is returned as a non-negative integer. Note that if the *sequence* is an array with a fill pointer, then `length` returns the value of the fill pointer (see `array-active-length` (page 161)), not the total storage space for the array. the total

`fill` *sequence item* `&optional` *start end* [*Function*]

The *sequence* is destructively modified by replacing some or all of its elements with the *item*. The *item* may be any LISP object, but must be a suitable element for the *sequence*. The *item* is stored into all the components of the *sequence*, beginning at the one specified by the index *start*, and up to but not including the one specified by the index *end*. The *start* index defaults to zero, and the end index to the length of the *sequence*. `fill` returns the modified *sequence*.

For example:

```
(setq x (vector 'a 'b 'c 'd 'e)) => #(a b c d e)
(fill x 'z 1 3) => #(a z z d e)
  and now x => #(a z z d e)
(fill x 'p) => #(p p p p p)
  and now x => #(p p p p p)
```

`replace` *target-sequence source-sequence* `&optional` *target-start target-end source-start source-end* [*F*

The *target-sequence* is destructively modified by copying successive elements into it from *source-sequence*. The elements of *source-sequence* must be of a type that may be stored into the *target-sequence*. The leftmost element modified is specified by the index *target-start*, which defaults to zero; the leftmost element copied is specified by the index *source-start*, which also defaults to zero. The index *target-end* limits the region of *target-sequence* which is modified; it defaults to the length of the *target-sequence*. *source-end* limits the region of *source-sequence* which is copied; it defaults to the length of the *source-sequence*. The indices must all be integers and satisfy the relationships

```
(<= 0 target-start target-end (length target-sequence))
(<= 0 source-start source-end (length source-sequence)).
```

The number of elements copied may be expressed as:

```
(min (- target-end target-start) (- source-end source-start))
```

The value returned by `replace` is the modified *target-sequence*.

If *target-sequence* and *source-sequence* are the same object and the region being modified overlaps with the region being copied from, then it is as if the entire source region were copied to another place and only then copied back into the target region.

`reverse` *sequence* [*Function*]

The result is a new sequence of the same kind as *sequence*, containing the same elements but in reverse order. The argument is not modified.

`nreverse` *sequence* [*Function*]

The result is a sequence containing the same elements as *sequence* but in reverse order. The argument may be destroyed and re-used to produce the result. The result may or may not be `eq` to the argument, so it is usually wise to say something like `(setq x (nreverse x))`, because simply `(nreverse x)` is not guaranteed to leave a reversed value in `x`.

`catenate &rest` *sequences* [*Function*]

The result is a new sequence which contains all the elements of all the sequences in order. All of the sequences are copied from; the result does not share any structure with any of the argument sequences (in this `catenate` differs from `append`).

The type of the result may depend to some extent on the implementation. As a rule it should be the least general sequence type among those the implementation provides which can contain the elements of all the argument sequences. The implementation must be such that `catenate` is

associative, in the sense that the elements of the result sequence are not affected by reassociation (but the type of the result sequence may be affected). If no arguments are provided, `catenate` returns `()`.

`map` *function result-type sequence* `&rest` *more-sequences* [*Function*]

The *function* must take as many arguments as there are sequences provided; at least one sequence must be provided. The result of `map` is a sequence such that element *j* is the result of applying *function* to element *j* of each of the argument sequences. The result sequence is as long as the shortest of the input sequences.

If the *function* has side-effects, it can count on being called first on all the elements numbered `0`, then on all those numbered `1`, and so on.

The type of the result sequence is specified by the argument *result-type*.

> Compatibility note: In MACLISP, Lisp Machine LISP, INTERLISP, and indeed even LISP 1.5, the function `map` has always meant a non-value-returning version. In my opinion they blew it. I suggest that for COMMON LISP this should be corrected, as the names `map` and `reduce` have become quite common in the literature, `map` always meaning what in the past LISP people have called `mapcar`. It would simplify things in the future to make the standard (according to the rest of the world) name `map` do the standard thing. Therefore the old `map` function is here renamed `map1` (page 66).

For example:

```
(map #'- 'list '(1 2 3 4)) => (-1 -2 -3 -4)
(map #'(lambda (x) (if (oddp x) 1 0)) 'bit-string '(1 2 3 4)) =
```

`some` *predicate sequence* `&rest` *more-sequences* [*Function*]
`every` *predicate sequence* `&rest` *more-sequences* [*Function*]
`notany` *predicate sequence* `&rest` *more-sequences* [*Function*]
`notevery` *predicate sequence* `&rest` *more-sequences* [*Function*]

These are all predicates. The *predicate* must take as many arguments as there are sequences provided. The *predicate* is first applied to the elements with index `0` in each of the sequences, and possibly then to the elements with index `1`, and so on, until a termination criterion is met or the end of the shortest of the *sequences* is reached.

`some` returns as soon as any invocation of *predicate* returns a non-`()` value; `some` returns that value. If the end of a sequence is reached, `some` returns `()`. Thus as a predicate it is true if *some* invocation of *predicate* is true.

`every` returns `()` as soon as any invocation of *predicate* returns `()`. If the end of a sequence is reached, `every` returns a non-`()` value.. Thus as a predicate it is true if *every* invocation of *predicate* is true.

`notany` returns `()` as soon as any invocation of *predicate* returns a non-`()` value. If the end of a sequence is reached, `notany` returns a non-`()` value. Thus as a predicate it is true if *no* invocation of *predicate* is true.

`notevery` returns a non-`()` value as soon as any invocation of *predicate* returns `()`. If the end of

a sequence is reached, `notevery` returns `()`. Thus as a predicate it is true if *not every* invocation of *predicate* is true.

Compatibility note: The order of the arguments here is not compatible with INTERLISP and Lisp Machine LISP. This is to stress the similarity of these functions to `map`. The functions are therefore extended here to functions of more than one argument, and multiple sequences.

`remove` *item sequence* `&optional` *count* [*Function*]
`remq` *item sequence* `&optional` *count* [*Function*]
`rem` *predicate item sequence* `&optional` *count* [*Function*]
`rem-if` *predicate sequence* `&optional` *count* [*Function*]
`rem-if-not` *predicate sequence* `&optional` *count* [*Function*]
`remove-from-end` *item sequence* `&optional` *count* [*Function*]
`remq-from-end` *item sequence* `&optional` *count* [*Function*]
`rem-from-end` *predicate item sequence* `&optional` *count* [*Function*]
`rem-from-end-if` *predicate sequence* `&optional` *count* [*Function*]
`rem-from-end-if-not` *predicate sequence* `&optional` *count* [*Function*]

The result is a sequence of the same kind as the argument *sequence*, which has the same elements except that those satisfying a certain test have been removed. This is a nondestructive operation; the result is a copy of the input *sequence*, save that some elements are not copied.

For `remove`, an element is removed if *item* is `equal` to it.

For `remq`, an element is removed if *item* is `eq` to it.

For `rem`, an element is removed is *predicate* is true when applied to *item* and an element (in that order).

For `rem-if`, an element is removed if *predicate* is true of it.

For `rem-if-not`, an element is removed if *predicate* is not true of it.

The argument *count*, if supplied, limits the number of elements removed; if more elements than *count* satisfy the test, only the leftmost *count* such are removed.

The `-from-end` variants differ from the others only when *count* is provided; in that case only the rightmost *count* elements satisfying the test are removed.

For example:

```
(remove 4 '(1 2 4 1 3 4 5)) => (1 2 1 3 5)
(remove 4 '(1 2 4 1 3 4 5) 1) => (1 2 1 3 4 5)
(remove-from-end 4 '(1 2 4 1 3 4 5) 1) => (1 2 4 1 3 5)
(rem #'> 3 '(1 2 4 1 3 4 5)) => (4 3 4 5)
(rem-if #'oddp '(1 2 4 1 3 4 5)) => (2 4 4)
(rem-from-end-if #'evenp '(1 2 4 1 3 4 5) 1) => (1 2 4 1 3 5)
```

The result of `remove` and related functions may share with the argument *sequence*; a list result may share a tail with an input list, and the result may be `eq` to the input *sequence* if no elements need to be removed.

`position` *item sequence* `&optional` *start end* [*Function*]
`posq` *item sequence* `&optional` *start end* [*Function*]
`pos` *predicate item sequence* `&optional` *start end* [*Function*]
`pos-if` *predicate sequence* `&optional` *start end* [*Function*]
`pos-if-not` *predicate sequence* `&optional` *start end* [*Function*]
`position-from-end` *item sequence* `&optional` *start end* [*Function*]
`posq-from-end` *item sequence* `&optional` *start end* [*Function*]
`pos-from-end` *predicate item sequence* `&optional` *start end* [*Function*]
`pos-from-end-if` *predicate sequence* `&optional` *start end* [*Function*]
`pos-from-end-if-not` *predicate sequence* `&optional` *start end* [*Function*]

If the *sequence* contains an element satisfying a certain test, then the index within the sequence of the leftmost such element is returned as a non-negative integer; otherwise ( ) is returned.

For `position`, an element passes the test if *item* is `equal` to it.

For `posq`, an element passes the test if *item* is `eq` to it.

For `pos`, an element passes the test is *predicate* is true when applied to *item* and an element (in that order).

For `pos-if`, an element passes the test if *predicate* is true of it.

For `pos-if-not`, an element passes the test if *predicate* is not true of it.

The `-from-end` variants differ in that the index of the *rightmost* element passing the test, if any, is returned.

The implementation may choose to scan the sequence in any order; there is no guarantee on the number of times the test is made. For example, `position-from-end` might scan a list from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

The arguments *start* and *end* limit the search to the specified subsequence; as usual, *start* defaults to zero and *end* to the length of the sequence.

`count` *item sequence* `&optional` *start end* [*Function*]
`cntq` *item sequence* `&optional` *start end* [*Function*]
`cnt` *predicate item sequence* `&optional` *start end* [*Function*]
`cnt-if` *predicate sequence* `&optional` *start end* [*Function*]
`cnt-if-not` *predicate sequence* `&optional` *start end* [*Function*]

The result is always a non-negative integer, the number of elements in the *sequence* satisfying a certain test.

For `count`, an element passes the test if *item* is `equal` to it.

For `cntq`, an element passes the test if *item* is `eq` to it.

For `cnt`, an element passes the test is *predicate* is true when applied to *item* and an element (in that

order).

For `cnt-if`, an element passes the test if *predicate* is true of it.

For `cnt-if-not`, an element passes the test if *predicate* is not true of it.

There is no guarantee on the number of times a user-supplied *predicate* will be called. For example, a tricky implementation for bit-strings might call the predicate once each on the values 0 and *1*, assume that those results are valid for all calls on 0 and 1, and then just count the actual bits and return an appropriate result. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

The arguments *start* and *end* limit the search to the specified subsequence; as usual, *start* defaults to zero and *end* to the length of the sequence.

`mismatch` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`mismatq` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`mismat` *predicate sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`mismatch-from-end` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`mismatq-from-end` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`mismat-from-end` *predicate sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]

The arguments *sequence1* and *sequence2* are compared element-wise. If they are of equal length and match in every element, the result is `()`. Otherwise, the result is a non-negative integer, the index of the leftmost position at which they fail to match; or, if one is shorter than and a matching prefix of the other, the length of the shorter sequence is returned.

For `mismatch`, elements are compared using `equal`.

For `mismatq`, elements are compared using `eq`.

For `mismat`, elements are compared by passing an element of *sequence1* and an element of *sequence2* (in that order) to a user-specified *predicate*.

The arguments *start1* and *end1* delimit a subsequence of *sequence1* to be matched, and *start2* and *end2* delimit a subsequence of *sequence2*. As usual, *start1* and *start2* default to zero, *end1* to the length of *sequence1*, and *end2* to the length of *sequence2*. The comparison proceeds by first aligning the left-hand ends of the two subsequences; the index returned is an index into *sequence1*. `mismatch` is therefore not commutative if *start1* and *start2* are not equal.

The `-from-end` variants differ in that the index of the *rightmost* position in which the sequences differ is returned. The (sub)sequences are aligned at their right-hand ends; the last elements are compared, the penultimate elements, and so on. The index returned is again an index into *sequence1*. If the first sequence is a proper suffix of the second, zero is returned; if the second is a proper suffix of the first, the length of the first less the that of the second is returned.

The implementation may choose to match the sequences in any order; there is no guarantee on the

number of times the test is made. For example, `mismatch-from-end` might match a list from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

`maxprefix` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`maxprefq` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`maxpref` *predicate sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`maxsuffix` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`maxsuffq` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`maxsuff` *predicate sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]

The arguments *sequence1* and *sequence2* are compared element-wise. The result is a non-negative integer, the index of the leftmost position at which they fail to match; or, if one is shorter than and a matching prefix of the other, the length of the shorter sequence is returned. If they are of equal length and match in every element, the result is the length of each.

For `maxprefix`, elements are compared using `equal`.

For `maxprefq`, elements are compared using `eq`.

For `maxpref`, elements are compared by passing an element of *sequence1* and an element of *sequence2* (in that order) to a user-specified *predicate*.

The arguments *start1* and *end1* delimit a subsequence of *sequence1* to be matched, and *start2* and *end2* delimit a subsequence of *sequence2*. As usual, *start1* and *start2* default to zero, *end1* to the length of *sequence1*, and *end2* to the length of *sequence2*. The comparison proceeds by first aligning the left-hand ends of the two subsequences; the index returned is an index into *sequence1*. `maxprefix` is therefore not commutative if *start1* and *start2* are not equal.

The `suffix` and `suff` variants differ in that 1 plus the index of the *rightmost* position in which the sequences differ is returned. The (sub)sequences are aligned at their right-hand ends; the last elements are compared, the penultimate elements, and so on. The index returned is again an index into *sequence1*. If the first sequence is a proper suffix of the second, zero is returned; if the second is a proper suffix of the first, the length of the first less that of the second is returned.

The implementation may choose to match the sequences in any order; there is no guarantee on the number of times the test is made. For example, `maxsuffix` might match lists from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

`search` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`srchq` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`srch` *predicate sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`search-from-end` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`srchq-from-end` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`srch-from-end` *predicate sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]

A search is conducted for a subsequence of *sequence2* which element-wise matches *sequence1*. If there is no such subsequence, the result is `()`; if there is, the result is the index into *sequence2* of the leftmost element of the leftmost such matching subsequence.

For `search`, elements are compared using `equal`.

For `srchq`, elements are compared using `eq`.

For `srch`, elements are compared by passing an element of *sequence1* and an element of *sequence2* (in that order) to a user-specified *predicate*.

The arguments *start1* and *end1* delimit a subsequence of *sequence1* to be matched, and *start2* and *end2* delimit a subsequence of *sequence2* to be searched. As usual, *start1* and *start2* default to zero, *end1* to the length of *sequence1*, and *end2* to the length of *sequence2*.

The `-from-end` variants differ in that the index of the leftmost element of the *rightmost* matching subsequence is returned.

The implementation may choose to cnt the sequence in any order; there is no guarantee on the number of times the test is made. For example, `search-from-end` might cnt a list from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

`sort` *sequence predicate* `&optional` *selector* [*Function*]
`stable-sort` *sequence predicate* `&optional` *selector* [*Function*]

The *sequence* is destructively sorted according to an ordering determined by the *predicate*. The *predicate* should take two arguments, and return non-`()` if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *predicate* should return `()`.

The `sort` function determines the relationship between two elements by giving keys extracted from the elements to the *predicate*. The function *selector*, when applied to an element, should return the key for that element; the *selector* function defaults to the identity function, thereby making the element itself be the key.

The *selector* function should not have any side effects. A useful example of a *selector* function would be a component selector function for a `defstruct` (page 167) structure, for sorting a sequence of structures.

```
(sort a p s)
   <=> (sort a #'(lambda (x y) (p (s x) (s y))))
```

While the above two expression are equivalent, the first may be more efficient in some implementations for certain types of arguments. For example, an implementation may choose to apply *selector* to each item just once, putting the resulting keys into a separate table, and then sort the parallel tables, as opposed to applying *selector* to an item every time just before applying the *predicate*.

If the *selector* and *predicate* functions always return, then the sorting operation will always terminate, producing a sequence containing the same elements as the original sequence (that is, the result is a permutation of *sequence*). This is guaranteed even if the *predicate* does not really consistently represent a total order. If the *selector* consistently returns meaningful keys, and the *predicate* does reflect some total ordering criterion on those keys, then the elements of the result sequence will conform to that ordering.

The sorting operation performed by `sort` is not guaranteed *stable*, however; elements considered equal by the *predicate* may or may not stay in their original order. The function `stable-sort` guarantees stability, but may be somewhat slower.

The sorting operation may be destructive in all cases. In the case of an array argument, this is accomplished by permuting the elements. In the case of a list, the list is destructively reordered in the same manner as for `nreverse` (page 89). Thus if the argument should not be destroyed, the user must sort a copy of the argument.

Should the *selector* or *predicate* cause an error, the state of the list or array being sorted is undefined. However, if the error is corrected the sort will, of course, proceed correctly.

Note that since sorting requires many comparisons, and thus many calls to the *predicate*, sorting will be much faster if the *predicate* is a compiled function rather than interpreted.

For example:

```
(defun mostcar (x)
    (if (symbolp x) x (mostcar (car x))))

(sort fooarray #'string-lessp #'mostcar)
```

If `fooarray` contained these items before the sort:

```
(Tokens (The lion sleeps tonight))
(Carpenters (Close to you))
((Rolling Stones) (Brown sugar))
((Beach Boys) (I get around))
(Beatles (I want to hold your hand))
```

then after the sort `fooarray` would contain:

```
((Beach Boys) (I get around))
(Beatles (I want to hold your hand))
(Carpenters (Close to you))
((Rolling Stones) (Brown sugar))
(Tokens (The lion sleeps tonight))
```

`merge` *sequence1 sequence2 predicate* `&optional` *selector* [*Function*]

The sequences *sequence1* and *sequence2* are destructively merged according to an ordering determined by the *predicate*. The *predicate* should take two arguments, and return non-`()` if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *predicate* should return `()`.

The `merge` function determines the relationship between two elements by giving keys extracted from the elements to the *predicate*. The function *selector*, when applied to an element, should return the key for that element; the *selector* function defaults to the identity function, thereby making the element itself be the key.

The *selector* function should not have any side effects. A useful example of a *selector* function would be a component selector function for a `defstruct` (page 167) structure, for merging a sequence of structures.

If the *selector* and *predicate* functions always return, then the merging operation will always terminate. The result of merging two sequences *x* and *y* is a new sequence *z* such that the length of *z* is the sum of the lengths of *x* and *y*, and *z* contains the all the elements of *x* and *y*. If *x1* and *x2* are two elements of *x*, and *x1* precedes *x2* in *x*, then *x1* precedes *x2* in *z*; similarly for elements of *y*. In other words, *z* is an *interleaving* of *x* and *y*.

Moreover, if *x* and *y* were correctly sorted according to the *predicate*, then *z* will also be correctly sorted. If *x* or *y* is not so sorted, then *z* will not be sorted, but will nevertheless be an interleaving of *x* and *y*.

The merging operation is guaranteed *stable*; if two or more elements are considered equal by the *predicate*, then the elements from *sequence1* will precede those from *sequence2* in the result.

Implementation note: To guarantee stability, one should give elements of *sequence2* as the *first* argument to the *predicate*, and elements of *sequence1* as the *second* argument.

For example:

```
(merge '(1 3 4 6 7) '(2 5 8) #'<) => (1 2 3 4 5 6 7 8)
```

Chapter 10

Sequences (Functional Version)

This chapter is one of several parallel chapters on sequences. The assumption is that one will be chosen to define the official set of COMMON LISP sequence functions. Reviewers of this draft are encouraged to compare these parallel chapters carefully.

The type `sequence` encompasses both lists and one-dimensional arrays. While these are different data structures with different structural properties leading to different algorithmic uses, they do have a common property: each contains contain an ordered set of elements.

There are some operations which are useful on both lists and arrays because they deal with ordered sets of elements. One may ask the number of elements, reverse the ordering, extract a subsequence, and so on. For such purposes COMMON LISP provides a set of generic functions on sequences:

`elt`	`reverse`	`map`	`remove`	`remove-duplica`
`setelt`	`nreverse`	`some`	`delete`	`delete-duplica`
`subseq`	`concat`	`every`	`position`	`find`
`copyseq`	`length`	`notany`	`mismatch`	`substitute`
`fill`	`sort`	`notevery`	`maxprefix`	`search`
`replace`	`merge`		`maxsuffix`	`count`

Some of these operations come in more than one version. Such versions are indicated by adding prefixes or suffixes to the basic name of the operation.

If the operation requires testing sequence elements according to some criterion, then the criterion may be specified in one of two ways. The basic operation accepts an item, and elements are tested for being `eql` to that item. The other version is a functional (indicated by prefixing the name with "`f`"). The functional takes a predicate and optionally some other arguments. The functional returns a function to perform the desired operation. This function will test elements of its sequence argument by calling the predicate, giving it the sequence element and also any extra arguments originally given to the functional, in that order. As an example,

`(remove` *item sequence*`)`

returns a copy of *sequence* from which all elements `eql` to *item* have been removed;

`((fremove #'equal` *item*`)` *sequence*`)`

returns a copy of *sequence* from which all elements `equal` to *item* have been removed;

`((fremove #'numberp)` *sequence*`)`

returns a copy of *sequence* from which all numbers have been removed; and

`((fremove #'fuzzy=` *number tolerance*`)` *sequence*`)`

returns a copy of *sequence* from which all elements fuzzily equal to *number* to with *tolerance* have been removed.

For some operations it can be useful to specify the direction in which the sequence is processed. In this case the basic operation processes the sequence in the forward direction, and processing in the reverse direction is indicated by the suffix "`-from-end`". Thus, for example, there are actually four kinds of `remove` functions: `remove`, `fremove`, `remove-from-end`, and `fremove-from-end`.

Many operations allow the specification of a subsequence to be operated upon. Such operations have arguments (optional, as a rule) called *start* and *end*. These arguments should be integer indices into the sequence, with *start*≤*end*; they indicate the subsequence starting with and including element *start* and up to but excluding element *end*. The length of the subsequence is therefore *end*−*start*. If *start* is omitted it defaults to zero, and if *end* is omitted or `()` it defaults to the length of the sequence; therefore if both are omitted the entire sequence is processed by default. For the most part this is permitted purely for the sake of efficiency; one can simply call `subseq` instead to extract the subsequence before operating on it. However, operations which produce indices return indices into the original sequence, not into the subsequence.

```
(position #/b "foobar" 2 5) => 3
(position #/b (subseq "foobar" 2 5)) => 1
```

`elt` *sequence index* [*Function*]

This returns the element of *sequence* specified by *index*, which must be a non-negative integer less than the length of the *sequence*. The first element of a sequence has index `0`.

`setelt` *sequence index newvalue* [*Function*]

The object *newvalue* is stored into the component of the *sequence* specified by *index*, which must be a non-negative integer less than the length of the *sequence*. The first element of any sequence has index `0`. If *sequence* is a specialized array, then the *newvalue* must be an object which that array can contain.

`subseq` *sequence start* `&optional` *end* [*Function*]

This returns the subsequence of *sequence* specified by *start* and *end*. `subseq` *always* allocates a new sequence for a result; it never shares storage with an old sequence. The result subsequence is always of the same type as the argument *sequence*.

`copyseq` *sequence* [*Function*]

A copy is made of the argument *sequence*; the result is `equal` to the argument but not `eq` to it.

`(copyseq` *x*`)` `<=>` `(subseq` *x* `0)`

but the name `copyseq` is more perspicuous when applicable.

`length` *sequence* [*Function*]

The number of elements in *sequence* is returned as a non-negative integer.

`fill` *sequence item* `&optional` *start end* [*Function*]

The *sequence* is destructively modified by replacing the elements of the subsequence specified by *start* and *end* with the *item*. The *item* may be any LISP object, but must be a suitable element for the *sequence*. The *item* is stored into all specified components of the *sequence*, beginning at the one specified by the index *start*, and up to but not including the one specified by the index *end*. `fill` returns the modified *sequence*.

For example:

```
(setq x (vector 'a 'b 'c 'd 'e)) => #(a b c d e)
(fill x 'z 1 3) => #(a z z d e)
  and now x => #(a z z d e)
(fill x 'p) => #(p p p p p)
  and now x => #(p p p p p)
```

`replace` *target-sequence source-sequence* `&optional` *target-start target-end source-start source-end*[*F*

The *target-sequence* is destructively modified by copying successive elements into it from *source-sequence*. The elements of *source-sequence* must be of a type that may be stored into the *target-sequence*. The subsequence of *source-sequence* specified by *source-start* and *source-end* is copied into the subsequence of *target-sequence* specified by *target-start* and *target-end*. If these subsequences are not of the same length, then the shorter length determines how many elements are copied; the extra elements near the end of the longer subsequence are not involved in the operation. The number of elements copied may be expressed as:

`(min (-` *target-end target-start*`) (-` *source-end source-start*`))`

The value returned by `replace` is the modified *target-sequence*.

If *target-sequence* and *source-sequence* are the same object and the region being modified overlaps with the region being copied from, then it is as if the entire source region were copied to another place and only then copied back into the target region.

`reverse` *sequence* [*Function*]

The result is a new sequence of the same kind as *sequence*, containing the same elements but in reverse order. The argument is not modified.

`nreverse` *sequence* [*Function*]

The result is a sequence containing the same elements as *sequence* but in reverse order. The argument may be destroyed and re-used to produce the result. The result may or may not be `eq` to the argument, so it is usually wise to say something like `(setq x (nreverse x))`, because simply `(nreverse x)` is not guaranteed to leave a reversed value in `x`.

`catenate &rest` *sequences* [*Function*]

The result is a new sequence which contains all the elements of all the sequences in order. All of the sequences are copied from; the result does not share any structure with any of the argument sequences (in this `catenate` differs from `append`).

The type of the result may depend to some extent on the implementation. As a rule it should be the least general sequence type among those the implementation provides which can contain the elements of all the argument sequences. The implementation must be such that `catenate` is associative, in the sense that the elements of the result sequence are not affected by reassociation (but the type of the result sequence may be affected). If no arguments are provided, `catenate` returns `()`.

`map` *result-type function sequence* `&rest` *more-sequences* [*Function*]

The *function* must take as many arguments as there are sequences provided; at least one sequence must be provided. The result of `map` is a sequence such that element *j* is the result of applying *function* to element *j* of each of the argument sequences. The result sequence is as long as the shortest of the input sequences.

If the *function* has side-effects, it can count on being called first on all the elements numbered 0, then on all those numbered 1, and so on.

The type of the result sequence is specified by the argument *result-type*.

> Compatibility note: In MACLISP, Lisp Machine LISP, INTERLISP, and indeed even LISP 1.5, the function `map` has always meant a non-value-returning version. In my opinion they blew it. I suggest that for COMMON LISP this should be corrected, as the names `map` and `reduce` have become quite common in the literature, `map` always meaning what in the past LISP people have called `mapcar`. It would simplify things in the future to make the standard (according to the rest of the world) name `map` do the standard thing. Therefore the old `map` function is here renamed `mapl` (page 66).

For example:

```
(map 'list #'- '(1 2 3 4)) => (-1 -2 -3 -4)
(map 'bit-vector #'(lambda (x) (if (oddp x) 1 0)) '(1 2 3 4)) =
```

`some` *predicate sequence* `&rest` *more-sequences* [*Function*]
`every` *predicate sequence* `&rest` *more-sequences* [*Function*]
`notany` *predicate sequence* `&rest` *more-sequences* [*Function*]
`notevery` *predicate sequence* `&rest` *more-sequences* [*Function*]

These are all predicates. The *predicate* must take as many arguments as there are sequences provided. The *predicate* is first applied to the elements with index 0 in each of the sequences, and possibly then to the elements with index 1, and so on, until a termination criterion is met or the end of the shortest of the *sequences* is reached.

`some` returns as soon as any invocation of *predicate* returns a non-`()` value; `some` returns that value. If the end of a sequence is reached, `some` returns `()`. Thus as a predicate it is true if *some* invocation of *predicate* is true.

`every` returns `()` as soon as any invocation of *predicate* returns `()`. If the end of a sequence is

reached; `every` returns a non-`()` value.. Thus as a predicate it is true if *every* invocation of *predicate* is true.

`notany` returns `()` as soon as any invocation of *predicate* returns a non-`()` value. If the end of a sequence is reached, `notany` returns a non-`()` value. Thus as a predicate it is true if *no* invocation of *predicate* is true.

`notevery` returns a non-`()` value as soon as any invocation of *predicate* returns `()`. If the end of a sequence is reached, `notevery` returns `()`. Thus as a predicate it is true if *not every* invocation of *predicate* is true.

Compatibility note: The order of the arguments here is not compatible with INTERLISP and Lisp Machine LISP. This is to stress the similarity of these functions to `map`. The functions are therefore extended here to functions of more than one argument, and multiple sequences.

In the following function descriptions, an element *x* of a sequence "satisfies the test" if (`eql` *x item*) is true (for the basic version) or if (`funcall*` *predicate x arguments*) is true (for the functional version). Two elements *x* and *y* taken from sequences "match" if (`eql` *x y*) is true (for the basic version) or if (`funcall*` *predicate x y arguments*) is true (for the functional version).

`remove` *item sequence* `&optional` *count* [*Function*]
`fremove` (*predicate* `&rest` *arguments*) *sequence* `&optional` *count* [*Functional*]
`remove-from-end` *item sequence* `&optional` *count* [*Function*]
`fremove-from-end` (*predicate* `&rest` *arguments*) *sequence* `&optional` *count* [*Functional*]

The result is a sequence of the same kind as the argument *sequence*, which has the same elements except that those satisfying the test (see above) have been removed. This is a nondestructive operation; the result is a copy of the input *sequence*, save that some elements are not copied.

The argument *count*, if supplied, limits the number of elements removed; if more elements than *count* satisfy the test, only the leftmost *count* such are removed.

The `-from-end` variants differ from the others only when *count* is provided; in that case only the rightmost *count* elements satisfying the test are removed.

For example:

```
(remove 4 '(1 2 4 1 3 4 5)) => (1 2 1 3 5)
(remove 4 '(1 2 4 1 3 4 5) 1) => (1 2 1 3 4 5)
(remove-from-end 4 '(1 2 4 1 3 4 5) 1) => (1 2 4 1 3 5)
((fremove #'< 3) '(1 2 4 1 3 4 5)) => (4 3 4 5)
((fremove #'oddp) '(1 2 4 1 3 4 5)) => (2 4 4)
((fremove-from-end #'evenp) '(1 2 4 1 3 4 5) 1) => (1 2 4 1 3 5
```

The result of `remove` and related functions may share with the argument *sequence*; a list result may share a tail with an input list, and the result may be `eq` to the input *sequence* if no elements need to be removed.

`find` *item sequence* `&optional` *start end* [*Function*]
`ffind` (*predicate* `&rest` *arguments*) *sequence* `&optional` *start end* [*Functional*]
`find-from-end` *item sequence* `&optional` *start end* [*Function*]
`ffind-from-end` (*predicate* `&rest` *arguments*) *sequence* `&optional` *start end* [*Functional*]

If the specified subsequence of *sequence* contains an element satisfying the test, then the leftmost such element is returned as a non-negative integer; otherwise ( ) is returned.

The `-from-end` variants are similar, but return the *rightmost* element satisfying the test. (The index returned, however, is an index from the left-hand end, as usual.)

`position` *item sequence* `&optional` *start end* [*Function*]
`fposition` (*predicate* `&rest` *arguments*) *sequence* `&optional` *start end* [*Functional*]
`position-from-end` *item sequence* `&optional` *start end* [*Function*]
`fposition-from-end` (*predicate* `&rest` *arguments*) *sequence* `&optional` *start end* [*Functional*]

If the specified subsequence of *sequence* contains an element satisfying the test, then the index within the sequence of the leftmost such element is returned as a non-negative integer; otherwise ( ) is returned.

The `-from-end` variants are similar, but determine the position of the *rightmost* element satisfying the test. (The index returned, however, is an index from the left-hand end, as usual.)

`count` *item sequence* `&optional` *start end* [*Function*]
`fcount` (*predicate* `&rest` *arguments*) *sequence* `&optional` *start end* [*Functional*]

The result is always a non-negative integer, the number of elements in the *sequence* satisfying the test (see above).

`mismatch` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`fmismatch` (*predicate* `&rest` *arguments*) *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Functional*]
`mismatch-from-end` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`fmismatch-from-end` (*predicate* `&rest` *arguments*) *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Functional*]

The specified subsequences of *sequence1* and *sequence2* are compared element-wise. If they are of equal length and match in every element, the result is ( ). Otherwise, the result is a non-negative integer, the index within *sequence1* of the leftmost position at which they fail to match; or, if one is shorter than and a matching prefix of the other, the index within *sequence1* beyond the last position tested is returned.

The `-from-end` variants differ in that the index of the *rightmost* position in which the sequences differ is returned. The (sub)sequences are aligned at their right-hand ends; the last elements are compared, the penultimate elements; and so on. The index returned is again an index into *sequence1*.

`maxprefix` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`fmaxprefix` (*predicate* `&rest` *arguments*) *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Functional*]
`maxsuffix` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`fmaxsuffix` (*predicate* `&rest` *arguments*) *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Functional*]

The arguments *sequence1* and *sequence2* are compared element-wise. The result is a non-negative integer, which for `maxprefix` is the index of the leftmost position at which they fail to match; or, if one is shorter than and a matching prefix of the other, the length of the shorter sequence is returned. If they are of equal length and match in every element, the result is the length of each.

The arguments *start1* and *end1* delimit a subsequence of *sequence1* to be matched, and *start2* and *end2* delimit a subsequence of *sequence2*. The comparison proceeds by first aligning the left-hand ends of the two subsequences; the index returned is an index into *sequence1*. `maxprefix` is therefore not commutative if *start1* and *start2* are not equal.

The `suffix` versions differ in that 1 plus the index of the *rightmost* position in which the sequences differ is returned. The (sub)sequences are aligned at their right-hand ends; the last elements are compared, the penultimate elements, and so on. The index returned is again an index into *sequence1*.

The implementation may choose to match the sequences in any order; there is no guarantee on the number of times the test is made. For example, `maxsuffix` might match lists from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

`search` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`fsearch` (*predicate* `&rest` *arguments*) *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Functional*]
`search-from-end` *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Function*]
`fsearch-from-end` (*predicate* `&rest` *arguments*) *sequence1 sequence2* `&optional` *start1 start2 end1 end2* [*Functional*]

A search is conducted for a subsequence of *sequence2* that element-wise matches *sequence1*. If there is no such subsequence, the result is `()`; if there is, the result is the index into *sequence2* of the leftmost element of the leftmost such matching subsequence.

The `-from-end` variants differ in that the index of the leftmost element of the *rightmost* matching subsequence is returned.

The implementation may choose to search the sequence in any order; there is no guarantee on the number of times the test is made. For example, `search-from-end` might cnt a list from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

`sort` *sequence predicate* `&optional` *selector* [*Function*]
`stable-sort` *sequence predicate* `&optional` *selector* [*Function*]

The *sequence* is destructively sorted according to an ordering determined by the *predicate*. The *predicate* should take two arguments, and return non-`()` if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *predicate* should return `()`.

The `sort` function determines the relationship between two elements by giving keys extracted from the elements to the *predicate*. The function *selector*, when applied to an element, should return the key for that element; the *selector* function defaults to the identity function, thereby making the element itself be the key.

The *selector* function should not have any side effects. A useful example of a *selector* function would be a component selector function for a `defstruct` (page 167) structure, for sorting a sequence of structures.

```
(sort a p s)
   <=> (sort a #'(lambda (x y) (p (s x) (s y))))
```

While the above two expression are equivalent, the first may be more efficient in some implementations for certain types of arguments. For example, an implementation may choose to apply *selector* to each item just once, putting the resulting keys into a separate table, and then sort the parallel tables, as opposed to applying *selector* to an item every time just before applying the *predicate*.

If the *selector* and *predicate* functions always return, then the sorting operation will always terminate, producing a sequence containing the same elements as the original sequence (that is, the result is a permutation of *sequence*). This is guaranteed even if the *predicate* does not really consistently represent a total order. If the *selector* consistently returns meaningful keys, and the *predicate* does reflect some total ordering criterion on those keys, then the elements of the result sequence will conform to that ordering.

The sorting operation performed by `sort` is not guaranteed *stable*, however; elements considered equal by the *predicate* may or may not stay in their original order. The function `stable-sort` guarantees stability, but may be somewhat slower.

The sorting operation may be destructive in all cases. In the case of an array or vector argument, this is accomplished by permuting the elements. In the case of a list, the list is destructively reordered in the same manner as for `nreverse` (page 89). Thus if the argument should not be destroyed, the user must sort a copy of the argument.

Should the *selector* or *predicate* cause an error, the state of the list or array being sorted is undefined. However, if the error is corrected the sort will, of course, proceed correctly.

Note that since sorting requires many comparisons, and thus many calls to the *predicate*, sorting will be much faster if the *predicate* is a compiled function rather than interpreted.

For example:

```
(defun mostcar (x)
    (if (symbolp x) x (mostcar (car x))))

(sort fooarray #'string-lessp #'mostcar)
```

If `fooarray` contained these items before the sort:

```
(Tokens (The lion sleeps tonight))
(Carpenters (Close to you))
((Rolling Stones) (Brown sugar))
((Beach Boys) (I get around))
(Beatles (I want to hold your hand))
```

then after the sort `fooarray` would contain:

```
((Beach Boys) (I get around))
(Beatles (I want to hold your hand))
(Carpenters (Close to you))
((Rolling Stones) (Brown sugar))
(Tokens (The lion sleeps tonight))
```

`merge` *sequence1 sequence2 predicate* `&optional` *selector* [*Function*]

The sequences *sequence1* and *sequence2* are destructively merged according to an ordering determined by the *predicate*. The *predicate* should take two arguments, and return non-`()` if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *predicate* should return `()`.

The `merge` function determines the relationship between two elements by giving keys extracted from the elements to the *predicate*. The function *selector*, when applied to an element, should return the key for that element; the *selector* function defaults to the identity function, thereby making the element itself be the key.

The *selector* function should not have any side effects. A useful example of a *selector* function would be a component selector function for a `defstruct` (page 167) structure, for merging a sequence of structures.

If the *selector* and *predicate* functions always return, then the merging operation will always terminate. The result of merging two sequences x and y is a new sequence z such that the length of z is the sum of the lengths of x and y, and z contains the all the elements of x and y. If *x1* and *x2* are two elements of x, and *x1* precedes *x2* in x, then *x1* precedes *x2* in z; similarly for elements of y. In other words, z is an *interleaving* of x and y.

Moreover, if x and y were correctly sorted according to the *predicate*, then z will also be correctly sorted. If x or y is not so sorted, then z will not be sorted, but will nevertheless be an interleaving of x and y.

The merging operation is guaranteed *stable*; if two or more elements are considered equal by the *predicate*, then the elements from *sequence1* will precede those from *sequence2* in the result.

Implementation note: To guarantee stability, one should give elements of *sequence2* as the *first* argument to the *predicate*, and elements of *sequence1* as the *second* argument.

For example:

```
(merge '(1 3 4 6 7) '(2 5 8) #'<) => (1 2 3 4 5 6 7 8)
```

Chapter 11

Sequences (Keyword Version)

equal ?

This chapter is one of several parallel chapters on sequences. The assumption is that one will be chosen to define the official set of COMMON LISP sequence functions. Reviewers of this draft are encouraged to compare these parallel chapters carefully.

The type `sequence` encompasses both lists and one-dimensional arrays. While these are different data structures with different structural properties leading to different algorithmic uses, they do have a common property: each contains contain an ordered set of elements.

There are some operations which are useful on both lists and arrays because they deal with ordered sets of elements. One may ask the number of elements, reverse the ordering, extract a subsequence, and so on. For such purposes COMMON LISP provides a set of generic functions on sequences:

`elt`	`reverse`	`map`	`remove`	`remove-duplica`
`setelt`	`nreverse`	`some`	`delete`	`delete-duplica`
`subseq`	`concat`	`every`	`position`	`find`
`copyseq`	`length`	`notany`	`mismatch`	`substitute`
`fill`	`sort`	`notevery`	`maxprefix`	`search`
`replace`	`merge`		`maxsuffix`	`count`

Some of these operations come in more than one version. Such versions are indicated by adding a suffix to the basic name of the operation. In addition, many operations accept one or more optional keyword arguments that can modify the operation in various ways.

If the operation requires testing sequence elements according to some criterion, then the criterion may be specified in one of two ways. The basic operation accepts an item, and elements are tested for being `eql` to that item. (A test other than `eql` can be specified by the `:test` or `:test-not` keyword.) The variants formed by adding "`-if`" and "`-if-not`" to the basic operation name do not take an item, but instead a one-argument predicate, and elements are tested for satisfying or not satisfying the predicate. As an example,

`(remove` *item sequence*`)`

returns a copy of *sequence* from which all elements `eql` to *item* have been removed;

`(remove` *item sequence* `:test #'equal)`

returns a copy of *sequence* from which all elements `equal` to *item* have been removed;

`(remove-if #'numberp` *sequence*`)`

returns a copy of *sequence* from which all numbers have been removed; and

```
(remove-if #'(lambda (x) (fuzzy= x number tolerance)) sequence)
```

returns a copy of *sequence* from which all elements fuzzily equal to *number* to with *tolerance* have been removed.

If an operation tests elements of a sequence in any manner, the keyword argument `:key`, if not `()`, should be a function of one argument that will extract from an element the part to be tested in place of the whole element. For example, the effect of the MACLISP expression `(assq item seq)` could be obtained by

```
(find item sequence :test #'eq :key #'car)
```

This searches for the first element of *sequence* whose *car* is `eq` to *item*.

For some operations it can be useful to specify the direction in which the sequence is processed. In this case the basic operation normally processes the sequence in the forward direction, and processing in the reverse direction is indicated by a non-`()` value for the keyword argument `:from-end`.

Many operations allow the specification of a subsequence to be operated upon. Such operations have keyword arguments called `:start` and `:end`. These arguments should be integer indices into the sequence, with *start*≤*end*; they indicate the subsequence starting with and including element *start* and up to but excluding element *end*. The length of the subsequence is therefore *end*−*start*. If *start* is omitted it defaults to zero, and if *end* is omitted or `()` it defaults to the length of the sequence; therefore if both are omitted the entire sequence is processed by default. For the most part this is permitted purely for the sake of efficiency; one can simply call `subseq` instead to extract the subsequence before operating on it. However, operations which produce indices return indices into the original sequence, not into the subsequence.

```
(position #/b "foobar" :start 2 :end 5) => 3
(position #/b (subseq "foobar" 2 5)) => 1
```

If two sequences are involved, then the `:start` and `:end` values affect *both* sequences. Alternatively, the keyword arguments `:start1`, `:end1`, `:start2`, and `:end2` may be used to specify separate subsequences for each sequence.

For some functions, notably `remove` and `delete`, the keyword argument `:count` is used to specify how many occurrences of the item should be affected. If this is `()` or is not supplied, all matching items are affected.

`elt` *sequence index* [*Function*]

This returns the element of *sequence* specified by *index*, which must be a non-negative integer less than the length of the *sequence*. The first element of a sequence has index `0`.

`setelt` *sequence index newvalue* [*Function*]

The object *newvalue* is stored into the component of the *sequence* specified by *index*, which must be a non-negative integer less than the length of the *sequence*. The first element of any sequence has index `0`. If *sequence* is a specialized array, then the *newvalue* must be an object which that array can

contain.

`subseq` *sequence start* `&optional` *end* [*Function*]

This returns the subsequence of *sequence* specified by *start* and *end*. `subseq` *always* allocates a new sequence for a result; it never shares storage with an old sequence. The result subsequence is always of the same type as the argument *sequence*.

`copyseq` *sequence* [*Function*]

A copy is made of the argument *sequence*; the result is `equal` to the argument but not `eq` to it.

```
(copyseq x) <=> (subseq x 0)
```

but the name `copyseq` is more perspicuous when applicable.

`length` *sequence* [*Function*]

The number of elements in *sequence* is returned as a non-negative integer.

`fill` *sequence item* `&key &optional :start` *s* `:end` *e* [*Function*]

The *sequence* is destructively modified by replacing the elements of the subsequence specified by *s* and *e* with the *item*. The *item* may be any LISP object, but must be a suitable element for the *sequence*. The *item* is stored into all specified components of the *sequence*, beginning at the one specified by the index *s*, and up to but not including the one specified by the index *e*. `fill` returns the modified *sequence*.

For example:

```
(setq x (vector 'a 'b 'c 'd 'e)) => #(a b c d e)
(fill x 'z :start 1 :end 3) => #(a z z d e)
  and now x => #(a z z d e)
(fill x 'p) => #(p p p p p)
  and now x => #(p p p p p)
```

`replace` *sequence1 sequence2* `&key &optional :start` *s* `:end` *e* `:start1` *s1* `:end1` *e1* `:st`

The sequence *sequence1* is destructively modified by copying successive elements into it from *sequence2*. The elements of *sequence2* must be of a type that may be stored into *sequence1*. The subsequence of *sequence2* specified by *s2* and *e2* is copied into the subsequence of *sequence1* specified by *s1* and *e1*. (The arguments *s1* and *s2* default to *s*, which defaults to `0`. The arguments *e1* and *e2* default to *e*, which defaults to ( ), meaning the end of the appropriate sequence.) If these subsequences are not of the same length, then the shorter length determines how many elements are copied; the extra elements near the end of the longer subsequence are not involved in the operation. The number of elements copied may be expressed as:

```
(min (- e1 s1) (- e2 s2))
```

The value returned by `replace` is the modified *sequence1*.

If *sequence1* and *sequence2* are the same object and the region being modified overlaps with the

region being copied from, then it is as if the entire source region were copied to another place and only then copied back into the target region.

`reverse` *sequence* [*Function*]

The result is a new sequence of the same kind as *sequence*, containing the same elements but in reverse order. The argument is not modified.

`nreverse` *sequence* [*Function*]

The result is a sequence containing the same elements as *sequence* but in reverse order. The argument may be destroyed and re-used to produce the result. The result may or may not be `eq` to the argument, so it is usually wise to say something like `(setq x (nreverse x))`, because simply `(nreverse x)` is not guaranteed to leave a reversed value in `x`.

`catenate` *result-type* `&rest` *sequences* [*Function*]

The result is a new sequence which contains all the elements of all the sequences in order. All of the sequences are copied from; the result does not share any structure with any of the argument sequences (in this `catenate` differs from `append`). The type of the result is specified by *result-type*, which must be a subtype of `sequence`. It must be possible for every element of the argument sequences to be an element of a sequence of type result-*type*.

The implementation must be such that `catenate` is associative, in the sense that the elements of the result sequence are not affected by reassociation (but the type of the result sequence may be affected). If no arguments are provided, `catenate` returns the empty sequence of type *result-type*.

`map` *result-type function sequence* `&rest` *more-sequences* [*Function*]

The *function* must take as many arguments as there are sequences provided; at least one sequence must be provided. The result of `map` is a sequence such that element *j* is the result of applying *function* to element *j* of each of the argument sequences. The result sequence is as long as the shortest of the input sequences.

If the *function* has side-effects, it can count on being called first on all the elements numbered 0, then on all those numbered 1, and so on.

The type of the result sequence is specified by the argument *result-type*.

> **Compatibility note:** In MACLISP, Lisp Machine LISP, INTERLISP, and indeed even LISP 1.5, the function `map` has always meant a non-value-returning version. In my opinion they blew it. I suggest that for COMMON LISP this should be corrected, as the names `map` and `reduce` have become quite common in the literature, `map` always meaning what in the past LISP people have called `mapcar`. It would simplify things in the future to make the standard (according to the rest of the world) name `map` do the standard thing. Therefore the old `map` function is here renamed `map1` (page 66).

For example:

```
(map 'list #'- '(1 2 3 4)) => (-1 -2 -3 -4)
(map 'bit-vector #'(lambda (x) (if (oddp x) 1 0)) '(1 2 3 4)) =
```

`some` *predicate sequence* `&rest` *more-sequences* [*Function*]
`every` *predicate sequence* `&rest` *more-sequences* [*Function*]
`notany` *predicate sequence* `&rest` *more-sequences* [*Function*]
`notevery` *predicate sequence* `&rest` *more-sequences* [*Function*]

These are all predicates. The *predicate* must take as many arguments as there are sequences provided. The *predicate* is first applied to the elements with index 0 in each of the sequences, and possibly then to the elements with index 1, and so on, until a termination criterion is met or the end of the shortest of the *sequences* is reached.

`some` returns as soon as any invocation of *predicate* returns a non-`()` value; `some` returns that value. If the end of a sequence is reached, `some` returns `()`. Thus as a predicate it is true if *some* invocation of *predicate* is true.

`every` returns `()` as soon as any invocation of *predicate* returns `()`. If the end of a sequence is reached, `every` returns a non-`()` value.. Thus as a predicate it is true if *every* invocation of *predicate* is true.

`notany` returns `()` as soon as any invocation of *predicate* returns a non-`()` value. If the end of a sequence is reached, `notany` returns a non-`()` value. Thus as a predicate it is true if *no* invocation of *predicate* is true.

`notevery` returns a non-`()` value as soon as any invocation of *predicate* returns `()`. If the end of a sequence is reached, `notevery` returns `()`. Thus as a predicate it is true if *not every* invocation of *predicate* is true.

Compatibility note: The order of the arguments here is not compatible with INTERLISP and Lisp Machine LISP. This is to stress the similarity of these functions to `map`. The functions are therefore extended here to functions of more than one argument, and multiple sequences.

In the following function descriptions, an element *x* of a sequence "satisfies the test" if (*testfn item* (*keyfn* `x`)) is true (for the basic version with *testfn* specified by `:test`) or false (*testfn* specified by `:test-not`), or if (`funcall` *predicate* (*keyfn x*)) is true (for the `-if` version) or false (for the `-if-not` version), where *keyfn* is the value of the `:key` keyword argument (the default being the identity function).

??? **Query:** Should the default *testfn* be `eql` or `equal`?

Two elements *x* and *y* taken from sequences "match" if (*testfn* (*keyfn x*) (*keyfn y*)) is true (*testfn* specified by `:test`) or false (*testfn* specified by `:test-not`).

`remove` [*Function*]
, Nolabel]
`remove-if` [*Function*]
, Nolabel]
`remove-if-not` [*Function*]
, Nolabel] The result is a sequence of the same kind as the argument *sequence*, which has the same elements except that those in the subsequence delimited by *s* and *e* and satisfying the test (see

above) have been removed. This is a nondestructive operation; the result is a copy of the input *sequence*, save that some elements are not copied.

The `:count` argument, if supplied, limits the number of elements removed; if more than *c* elements satisfy the test, only the leftmost *c* such are removed.

A non-`()` `:from-end` specification matters only when the `:count` argument is provided; in that case only the rightmost *c* elements satisfying the test are removed.

For example:

```
(remove 4 '(1 2 4 1 3 4 5)) => (1 2 1 3 5)
(remove 4 '(1 2 4 1 3 4 5) :count 1) => (1 2 1 3 4 5)
(remove 4 '(1 2 4 1 3 4 5) :count 1 :from-end t) => (1 2 4 1 3
(remove 3 '(1 2 4 1 3 4 5) :test #'>) => (4 3 4 5)
(remove-if #'oddp '(1 2 4 1 3 4 5)) => (2 4 4)
(remove '(1 2 4 1 3 4 5) :count 1 :from-end t :test #'evenp)
   => (1 2 4 1 3 5)
```

The result of `remove` and related functions may share with the argument *sequence*; a list result may share a tail with an input list, and the result may be `eq` to the input *sequence* if no elements need to be removed.

`find` [*Function*]
, Nolabel]
`find-if` [*Function*]
, Nolabel]
`find-if-not` [*Function*]
, Nolabel] If the *sequence* contains an element satisfying the test, then the leftmost such element is returned; otherwise `()` is returned.

If `:start` and `:end` keyword arguments are given, only the specified subsequence of *sequence* is searched.

If a non-`()` `:from-end` keyword argument is specified, then the result is the *rightmost* element satisfying the test.

`position` [*Function*]
, Nolabel]
`position-if` [*Function*]
, Nolabel]
`position-if-not` [*Function*]
, Nolabel] If the *sequence* contains an element satisfying the test, then the index within the sequence of the leftmost such element is returned as a non-negative integer; otherwise `()` is returned.

If `:start` and `:end` keyword arguments are given, only the specified subsequence of *sequence* is searched. However, the index returned is relative to the entire sequence, not to the subsequence.

If a non-() :from-end keyword argument is specified, then the result is the index of the *rightmost* element satisfying the test. (The index returned, however, is an index from the left-hand end, as usual.)

`count` [*Function*]

, Nolabel]

`count-if` [*Function*]

, Nolabel]

`count-if-not` [*Function*]

, Nolabel] The result is always a non-negative integer, the number of elements in the specified subsequence of *sequence* satisfying the test (see above).

`mismatch` [*Function*]

, Nolabel] The specified subsequences of *sequence1* and *sequence2* are compared element-wise. If they are of equal length and match in every element, the result is (). Otherwise, the result is a non-negative integer, the index within *sequence1* of the leftmost position at which they fail to match; or, if one is shorter than and a matching prefix of the other, the index within *sequence1* beyond the last position tested is returned.

If a non-() :from-end keyword argument is given, then the index of the *rightmost* position in which the sequences differ is returned. The (sub)sequences are aligned at their right-hand ends; the last elements are compared, the penultimate elements, and so on. The index returned is again an index into *sequence1*.

`maxprefix` [*Function*]

, Nolabel]

`maxsuffix` [*Function*]

, Nolabel] The arguments *sequence1* and *sequence2* are compared element-wise. The result is a non-negative integer, which for `maxprefix` is the index of the leftmost position at which they fail to match; or, if one is shorter than and a matching prefix of the other, the length of the shorter sequence is returned. If they are of equal length and match in every element, the result is the length of each.

The keyword arguments `:start1` and `:end1` delimit a subsequence of *sequence1* to be matched, and `:start2` and `:end2` delimit a subsequence of *sequence2*. The comparison proceeds by first aligning the left-hand ends of the two subsequences; the index returned is an index into *sequence1*. `maxprefix` is therefore not commutative if `:start1` and `:start2` are not equal.

The `suffix` versions differ in that 1 plus the index of the *rightmost* position in which the sequences differ is returned. The (sub)sequences are aligned at their right-hand ends; the last elements are compared, the penultimate elements, and so on. The index returned is again an index into *sequence1*.

The implementation may choose to match the sequences in any order; there is no guarantee on the

number of times the test is made. For example, `maxsuffix` might match lists from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied *predicate* to be free of side-effects.

`search` [*Function*]

, Nolabel] A search is conducted for a subsequence of *sequence2* that element-wise matches *sequence1*. If there is no such subsequence, the result is `()`; if there is, the result is the index into *sequence2* of the leftmost element of the leftmost such matching subsequence.

If a non-`()` `:from-end` keyword argument is given, the index of the leftmost element of the *rightmost* matching subsequence is returned.

The implementation may choose to search the sequence in any order; there is no guarantee on the number of times the test is made. For example, `search-from-end` might cnt a list from left-to-right instead of from right-to-left. Therefore it is a good idea for a user-supplied predicate be free of side-effects.

`sort` *sequence predicate* `&key &optional :key` *k* [*Function*]
`stable-sort` *sequence predicate* `&key &optional :key` *k* [*Function*]

The *sequence* is destructively sorted according to an ordering determined by the *predicate*. The *predicate* should take two arguments, and return non-`()` if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *predicate* should return `()`.

The `sort` function determines the relationship between two elements by giving keys extracted from the elements to the *predicate*. The function *k*, when applied to an element, should return the key for that element; *k* defaults to the identity function, thereby making the element itself be the key.

The *selector* function should not have any side effects. A useful example of a *selector* function would be a component selector function for a `defstruct` (page 167) structure, for sorting a sequence of structures.

```
(sort a p :key s)
   <=> (sort a #'(lambda (x y) (p (s x) (s y))))
```

While the above two expression are equivalent, the first may be more efficient in some implementations for certain types of arguments. For example, an implementation may choose to apply *k* to each item just once, putting the resulting keys into a separate table, and then sort the parallel tables, as opposed to applying *k* to an item every time just before applying the *predicate*.

If the *k* and *predicate* functions always return, then the sorting operation will always terminate, producing a sequence containing the same elements as the original sequence (that is, the result is a permutation of *sequence*). This is guaranteed even if the *predicate* does not really consistently represent a total order. If the *k* consistently returns meaningful keys, and the *predicate* does reflect some total ordering criterion on those keys, then the elements of the result sequence will conform

to that ordering.

The sorting operation performed by `sort` is not guaranteed *stable*, however; elements considered equal by the *predicate* may or may not stay in their original order. The function `stable-sort` guarantees stability, but may be somewhat slower.

The sorting operation may be destructive in all cases. In the case of an array or vector argument, this is accomplished by permuting the elements. In the case of a list, the list is destructively reordered in the same manner as for `nreverse` (page 89). Thus if the argument should not be destroyed, the user must sort a copy of the argument.

Should execution of *k* or *predicate* cause an error, the state of the list or array being sorted is undefined. However, if the error is corrected the sort will, of course, proceed correctly.

Note that since sorting requires many comparisons, and thus many calls to the *predicate*, sorting will be much faster if the *predicate* is a compiled function rather than interpreted.

For example:

```
(defun mostcar (x)
    (if (symbolp x) x (mostcar (car x))))

(sort fooarray #'string-lessp :key #'mostcar)
```

If `fooarray` contained these items before the sort:

```
(Tokens (The lion sleeps tonight))
(Carpenters (Close to you))
((Rolling Stones) (Brown sugar))
((Beach Boys) (I get around))
(Beatles (I want to hold your hand))
```

then after the sort `fooarray` would contain:

```
((Beach Boys) (I get around))
(Beatles (I want to hold your hand))
(Carpenters (Close to you))
((Rolling Stones) (Brown sugar))
(Tokens (The lion sleeps tonight))
```

`merge` *sequence1 sequence2 predicate* `&key &optional :key` *k* [*Function*]

The sequences *sequence1* and *sequence2* are destructively merged according to an ordering determined by the *predicate*. The *predicate* should take two arguments, and return non-`()` if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *predicate* should return `()`.

The `merge` function determines the relationship between two elements by giving keys extracted from the elements to the *predicate*. The function *k*, when applied to an element, should return the key for that element; the *k* function defaults to the identity function, thereby making the element itself be the key.

The `:key` function should not have any side effects. A useful example of a `:key` function would

be a component selector function for a `defstruct` (page 167) structure, for merging a sequence of structures.

If the *k* and *predicate* functions always return, then the merging operation will always terminate. The result of merging two sequences *x* and *y* is a new sequence *z* such that the length of *z* is the sum of the lengths of *x* and *y*, and *z* contains the all the elements of *x* and *y*. If *x1* and *x2* are two elements of *x*, and *x1* precedes *x2* in *x*, then *x1* precedes *x2* in *z*; similarly for elements of *y*. In other words, *z* is an *interleaving* of *x* and *y*.

Moreover, if *x* and *y* were correctly sorted according to the *predicate*, then *z* will also be correctly sorted. If *x* or *y* is not so sorted, then *z* will not be sorted, but will nevertheless be an interleaving of *x* and *y*.

The merging operation is guaranteed *stable*; if two or more elements are considered equal by the *predicate*, then the elements from *sequence1* will precede those from *sequence2* in the result.

Implementation note: To guarantee stability, one should give elements of *sequence2* as the *first* argument to the *predicate*, and elements of *sequence1* as the *second* argument.

For example:

```
(merge '(1 3 4 6 7) '(2 5 8) #'<) => (1 2 3 4 5 6 7 8)
```

Chapter 12

Manipulating List Structure

A *cons*, or dotted pair, is a compound data object having two components, called the *car* and *cdr*. Each component may be any LISP object. A *list* is a chain of conses linked by *cdr* fields; the chain is terminated by some atom (a non-cons object). An ordinary list is terminated by `()`, the empty list. A list whose *cdr*-chain is terminated by some non-`()` atom is called a *dotted list*.

12.1. Conses

`car` *x* [*Function*]

Returns the *car* of *x*, which must be a cons or `()`; that is, *x* must satisfy the predicate `listp` (page 37). By definition, the *car* of `()` is `()`. If the cons is regarded as the first cons of a list, then `car` returns the first element of the list.

For example:

```
(car '(a b c)) => a
```

`cdr` *x* [*Function*]

Returns the *cdr* of *x*, which must be a cons or `()`; that is, *x* must satisfy the predicate `listp` (page 37). By definition, the *cdr* of `()` is `()`. If the cons is regarded as the first cons of a list, then `cdr` returns the rest of the list, which is a list with all elements but the first of the original list.

For example:

```
(cdr '(a b c)) => (b c)
```

`c...r` *x* [*Function*]

All of the compositions of up to four *car*'s and *cdr*'s are defined as functions in their own right. The names of these functions begin with "`c`" and end with "`r`", and in between is a sequence of "`a`" and "`d`" letters corresponding to the composition performed by the function.

For example:

`(cddadr x)` is the same as `(cdr (cdr (car (cdr x))))`

If the argument is regarded as a list, then `cadr` returns the second element of the list, `caddr` the third, and `cadddr` the fourth. If the first element of a list is a list, then `caar` is the first element of

the sublist, `cdar` is the rest of that sublist, and `cadar` is the second element of the sublist; and so on.

As a matter of style, it is often preferable to define a function or macro to access part of a complicated data structure, rather than to use a long `car/cdr` string:

```
(defmacro lambda-vars (lambda-exp) '(cadr ,lambda-exp))
    ;then use lambda-vars everywhere instead of cadr
```

See also `defstruct` (page 167), which will automatically declare new record data types and access functions for instances of them.

`cons` *x y* [*Function*]

`cons` is the primitive function to create a new *cons*, whose *car* is *x* and whose *cdr* is *y*.

For example:

```
(cons 'a 'b) => (a . b)
(cons 'a (cons 'b (cons 'c '()))) => (a b c)
(cons 'a '(b c d)) => (a b c d)
```

`cons` may be thought of as creating a *cons*, or as adding a new element to the front of a list.

`tree-equal` *x y* [*Function*]

This is a predicate which is true if *x* and *y* are isomorphic trees with identical leaves; that is, if *x* and *y* are `eq`, or if they are both conses and their *car*s are `tree-equal` and their *cdr*s are `tree-equal`. Thus `tree-equal` recursively compares conses (but not any other objects which have components). See `equal` (page 40), which does recursively compare other structured objects.

12.2. Lists

`list-length` *list* `&optional` *limit* [*Function*]

`list-length` returns, as an integer, the length of *list*. The length of a list is the number of top-level conses in it. If the argument *limit* is supplied, it should be an integer; if the length of the *list* is greater than *limit* (possibly because the *list* is circular!), then some integer no smaller than *limit* and no larger than the length of the list is returned.

Rationale: Allowing this vague definition of the meaning of *limit* allows certain tricky fast implementations.

For example:

```
(length '()) => 0
(length '(a b c d)) => 4
(length '(a (b c) d)) => 3
(length '(a b c d e f g) 4) => 4 or 5 or 6 or 7
```

`length` could be implemented by:

```
(defun list-length (x &optional (limit () limitp))
    (do ((n 0 (+ n 1))
         (y x (cdr y)))
        ((atom y) n)
      (when (and limitp (>= n limit))
        (return n))))
```

See `length` (page 88), which will return the length of any sequence.

`nth` *n list* [*Function*]

(`nth` *n list*) returns the *n*'th element of *list*, where the zeroth element is the *car* of the list. *n* must be a non-negative integer. If the length of the list is not greater than *n*, then the result is ( ). (This is consistent with the idea that the *car* and *cdr* of ( ) are each ( ).)

For example:

```
(nth 0 '(foo bar gack)) => foo
(nth 1 '(foo bar gack)) => bar
(nth 3 '(foo bar gack)) => ()
```

This function is slightly different from `list-elt` (page LIST-ELT-FUN); note also that the order of arguments is reversed.

Compatibility note: This is not the same as the INTERLISP function called `nth`, which is similar to but not exactly the same as the COMMON LISP function `nthcdr`. This definition of `nth` is compatible with Lisp Machine LISP and NIL. Also, some people have used macros and functions called `nth` of their own in their old MACLISP programs, which may not work the same way; be careful.

`nthcdr` *n list* [*Function*]

(`nthcdr` *n list*) performs the `cdr` operation *n* times on *list*, and returns the result.

For example:

```
(nthcdr 0 '(a b c)) => (a b c)
(nthcdr 2 '(a b c)) => (c)
(nthcdr 4 '(a b c)) => ()
```

In other words, it returns the *n*'th *cdr* of the list.

Compatibility note: This is similar to the INTERLISP function `nth`, except that the INTERLISP function is one-based instead of zero-based.

```
(car (nthcdr n x)) <=> (nth n x)
```

`last` *list* [*Function*]

`last` returns the last cons (*not* the last element!) of *list*. If *list* is ( ), it returns ( ).

For example:

```
(setq x '(a b c d))
(last x) => (d)
(rplacd (last x) '(e f))
x => '(a b c d e f)
(last '(a b c . d)) => (c . d)
```

`list &rest` *args* [*Function*]

`list` constructs and returns a list of its arguments.

For example:

```
(list 3 4 'a (car '(b . c)) (+ 6 -2)) => (3 4 a b 4)
```

`list*` *arg* `&rest` *others* [*Function*]

`list*` is like `list` except that the last *cons* of the constructed list is "dotted". The last argument to `list*` is used as the *cdr* of the last cons constructed; this need not be an atom. If it is not an atom, then the effect is to add several new elements to the front of a list.

For example:

```
(list* 'a 'b 'c 'd) => (a b c . d)
```
This is like
```
(cons 'a (cons 'b (cons 'c 'd)))
```
Also:
```
(list* 'a 'b 'c '(d e f)) => (a b c d e f)
(list* x) <=> x
```

`make-list` *size* `&optional` *value* [*Function*]

This creates and returns a list containing *size* elements, each of which is *value* (which defaults to `()`). *size* should be a non-negative integer.

For example:

```
(make-list 5) => (() () () () ())
(make-list 3 '() 'rah) => (rah rah rah)
```

Compatibility note: The Lisp Machine LISP function `make-list` takes arguments *area* and *size*. Areas are not relevant to COMMON LISP. The argument order used here is compatible with NIL.

`append &rest` *lists* [*Function*]

The arguments to `append` are lists. The result is a list which is the concatenation of the arguments. The arguments are not destroyed.

For example:

```
(append '(a b c) '(d e f) '() '(g)) => (a b c d e f g)
```

Note that `append` copies the top-level list structure of each of its arguments *except* the last. The function `list-concat` (page LIST-CONCAT-FUN) performs a similar operation, but copies all its arguments. See also `nconc` (page 92), which is like `append` but destroys all arguments but the last.

`(append` *x* `'())` is an idiom once frequently used to copy the list *x*, but the `copylist` function is more appropriate to this task.

`copylist` *list* [*Function*]

Returns a list which is `equal` to *list*, but not `eq`. Only the top level of list-structure is copied; that is, `copylist` copies in the *cdr* direction but not in the *car* direction. If the list is "dotted", that is, `(cdr (last` *list*`))` is a non-`()` atom, this will be true of the returned list also. See also `copyseq` (page 88).

`copyalist` *list* [*Function*]

`copyalist` is for copying association lists. The top level of list structure of *list* is copied, just as `copylist` does. In addition, each element of *list* which is a cons is replaced in the copy by a new cons with the same car and cdr.

`copytree` *object* [*Function*]

`copytree` is for copying trees of conses. The argument *object* may be any LISP object. If it is not a cons, it is returned; otherwise the result is a new cons of the results of calling `copytree` on the car and cdr of the argument. In other words, all conses in the tree are copied recursively, stopping only when non-conses are encountered. Circularities and the sharing of substructure are *not* preserved.

`list-reverse` *list* [*Function*]

`list-reverse` creates a new list whose elements are the elements of *list* taken in reverse order. `list-reverse` does not modify its argument, unlike `list-nreverse` (page 91) which is faster but does modify its argument. If the *list* is dotted, the non-`()` atom at the end is discarded; `reverse` always produces a list ending in `()`.

For example:

```
(list-reverse '(a b (c d) e)) => (e (c d) b a)
```

See `reverse` (page 89), which can reverse any kind of sequence.

`revappend` *x y* [*Function*]

`(revappend` *x y*`)` is exactly the same as `(append (reverse` *x*`)` *y*`)` except that it is more efficient. Both *x* and *y* should be lists. The argument *x* is copied, not destroyed. Compare this with `nreconc` (page 92), which destroys its first argument.

`list-nreverse` *list* [*Function*]

`nreverse` reverses its argument, which should be a list. The argument is destroyed by `rplacd`'s all through the list (see `reverse`, which creates a new list rather than destroying its argument). If the *list* is dotted, the non-`()` atom at the end is discarded; `nreverse` always produces a list ending in `()`.

For example:

```
(setq x '(a b c))
(nreverse x) => (c b a)
```

At this point the precise value of x is implementation-dependent.

See nreverse (page 89), which can destructively reverse any kind of sequence.

`nconc &rest` *lists* [*Function*]

nconc takes lists as arguments. It returns a list which is the arguments concatenated together. The arguments are changed, rather than copied. (Compare this with append (page 122), which copies arguments rather than destroying them.)

For example:

```
(setq x '(a b c))
(setq y '(d e f))
(nconc x y) => (a b c d e f)
x => (a b c d e f)
```

Note, in the example,that the value of x is now different, since its last cons has been rplacd'd to the value of y. If one were then to evaluate (nconc x y) again, it would yield a piece of "circular" list structure, whose printed representation would be (a b c d e f d e f d e f ...), repeating forever.

`nreconc` *x y* [*Function*]

(nreconc *x y*) is exactly the same as (nconc (nreverse *x*) *y*) except that it is more efficient. Both *x* and *y* should be lists. The argument *x* is destroyed. Compare this with revappend (page 123).

`push` *item place* [*Macro*]

The form *place* should be the name of a generalized variable containing a list; *item* may refer to any LISP object. The *item* is consed onto the front of the list, and the augmented list is stored back into *place* and returned. The form *place* may be any form acceptable as a generalized variable to setf (page 50). If the list held in *place* is viewed as a push-down stack, then push pushes an element onto the top of the stack.

For example:

```
(setq x '(a (b c) d))
(push 5 (cadr x)) => (5 b c)   and now x => (a (5 b c) d)
```

The effect of (push *item place*) is roughly equivalent to

```
(setf place (cons item place))
```

except that the latter would evaluate any subforms of *place* twice, while push takes care to evaluate them only once. Moreover, for certain *place* forms push may be significantly more efficient than the setf version.

`pushnew` *item place* [*Macro*]

The form *place* should be the name of a generalized variable containing a list; *item* may refer to any LISP object. If the *item* is already a member of the list (as determined by eql comparisons), then the *item* is consed onto the front of the list, and the augmented list is stored back into *place* and returned; otherwise ( ) is returned. (Thus a pushnew form returns a truth value saying whether

item was new to the list or not.) The form *place* may be any form acceptable as a generalized variable to `setf` (page 50). If the list held in *place* is viewed as a set, then `pushnew` adjoins an element to the set; see `adjoin` (page 99).

For example:

```
(setq x '(a (b c) d))
(pushnew 5 (cadr x)) => (5 b c)  and now x => (a (5 b c) d)
(pushnew 'b (cadr x)) => ()  and x is unchanged
```

The effect of `(pushnew` *item place*`)` is roughly equivalent to (??? see `memql` (page MEMQL-FUN))

```
(and (not (memql item place))
     (setf place (cons item place)))
```

except that the latter would evaluate *item* twice and any subforms of *place* thrice, while `pushnew` takes care to evaluate them only once each. Moreover, for certain *place* forms `pushnew` may be significantly more efficient than the `setf` version.

??? Query: The other way to define `pushnew` is as

```
(setf place (adjoin item place))
```

but that doesn't act as a useful pseudo-predicate. However, it may compile into shorter code. What do people think?

`pop` *place* [*Macro*]

The form *place* should be the name of a generalized variable containing a list. The result of `pop` is the `car` of the contents of *place*, and as a side-effect the `cdr` of the contents is stored back into *place*. The form *place* may be any form acceptable as a generalized variable to `setf` (page 50). If the list held in *place* is viewed as a push-down stack, then `pop` pops an element from the top of the stack and returns it.

For example:

```
(setq stack '(a b c))
(pop stack) => a  and now stack => (b c)
```

The effect of `(pop` *place*`)` is roughly equivalent to

```
(prog1 (car place) (setf place (cdr place)))
```

except that the latter would evaluate any subforms of *place* thrice, while `pop` takes care to evaluate them only once. Moreover, for certain *place* forms `pop` may be significantly more efficient than the `setf` version.

`butlast` *list* [*Function*]

This creates and returns a list with the same elements as *list*, excepting the last *n* elements. *n* defaults to 1. The argument is not destroyed. If the *list* has fewer than *n* elements, then `()` is returned.

For example:

```
(butlast '(a b c d)) => (a b c)
(butlast '((a b) (c d)) => ((a b))
(butlast '(a)) => ()
(butlast nil) => ()
```

The name is from the phrase "all elements but the last".

`nbutlast` *list* [*Function*]

This is the destructive version of `butlast`; it changes the *cdr* of the cons $n+1$ from the end of the *list* to `()`. *n* defaults to 1. If the *list* has fewer than *n* elements, then `nbutlast` returns `()`, and the argument is not modified. (Therefore one normally writes `(setq a (nbutlast a))` rather than simply `(nbutlast a)`.)

For example:

```
(setq foo '(a b c d))
(nbutlast foo) => (a b c)
foo => (a b c)
(nbutlast '(a)) => ()
(nbutlast '()) => ()
```

??? Query: Do we really want `finota`, `laston`, and `ldiff`, given the existence of `sublist` (page SUBLIST-FUN)?

`buttail` *list sublist* [*Function*]

list should be a list, and *sublist* should be a sublist of *list*, i.e. one of the conses that make up *list*. `buttail` (meaning "all but the tail") will return a new list, whose elements are those elements of *list* that appear before *sublist*. If *sublist* is not a tail of *list*, then a copy of *list* is returned. The argument *list* is not destroyed.

For example:

```
(setq x '(a b c d e))
(setq y (cdddr x)) => (d e)
(buttail x y) => (a b c)
```

but

```
(buttail '(a b c d) '(c d)) => (a b c d)
```

since the sublist was not `eq` to any part of the list.

??? Query: I realize we voted to change the name from `ldiff` to `buttail`, but it seems senseless to be different from existing INTERLISP and Lisp Machine LISP usage. Can we reconsider?

`list-to-vector` *list* [*Function*]

`list-to-vector` constructs a vector of the same length as *list* and with the same corresponding elements, and returns the new vector. The inverse of this operation is `vector-to-list` (page VECTOR-TO-LIST-FUN).

`list-to-string` *list* [*Function*]

`list-to-string` constructs a string of the same length as *list* and with the same corresponding elements (which must all be characters satisfying `string-charp` (page 140)), and returns the new string. The inverse of this operation is `string-to-list` (page 153).

12.3. Alteration of List Structure

The functions `rplaca` and `rplacd` are used to make alterations in already-existing list structure; that is, to change the cars and cdrs of existing conses.

The structure is not copied but is physically altered; hence caution should be exercised when using these functions, as strange side-effects can occur if portions of list structure become shared unbeknownst to the programmer. The `nconc` (page 124), `nreverse` (page 89), `nreconc` (page 124), and `nbutlast` (page 126) functions already described, and the `delete` (page 98) family described later, have the same property. However, they are normally not used for this side-effect; rather, the list-structure modification is purely for efficiency and compatible non-modifying functions are provided.

`rplaca` *x y* [*Function*]

(`rplaca` *x y*) changes the car of *x* to *y* and returns (the modified) *x*. *x* should be a cons, but *y* may be any Lisp object.

For example:

```
(setq g '(a b c))
(rplaca (cdr g) 'd) => (d c)
Now g => (a d c)
```

`rplacd` *x y* [*Function*]

(`rplacd` *x y*) changes the cdr of *x* to *y* and returns (the modified) *x*. *x* should be a cons, but *y* may be any Lisp object.

For example:

```
(setq x '(a b c))
(rplacd x 'd) => (a . d)
Now x => (a . d)
```

Compatibility note: In COMMON LISP, as in MACLISP and Lisp Machine LISP, `rplacd` can not be used to set the property list of a symbol. The `setplist` (page SETPLIST-FUN) function is provided for this purpose.

`setnth` *n list newvalue* [*Function*]

Alters the *n*'th element of *list* to be *newvalue*, where the zeroth element is the *car* of the *list*. *n* must be a non-negative number less than the length of the list. *setnth* returns ( ). See `nth` (page 121).

```
(setnth n x v) <=> (progn (rplaca (nthcdr n x) v) ())
```

12.4. Substitution of Expressions

A number of functions are provided for performing substitutions within a tree. All take a tree and a description of old sub-expressions to be replaced by new ones. The functions form a semi-regular collection, according to these properties:

- Whether comparison of items is by `eq` or `equal`.
- Whether substitution is specified by two arguments or by an association list.
- Whether the tree is copied or modified.

These properties may be summarized as follows:

	Accepts two arguments, old and new		Accepts an association list
	Uses `equal`	Uses `eq`	Uses `eq`
Copies	`subst`	`substq`	`sublis`
Modifies	`nsubst`	`nsubstq`	`nsublis`

`subst` *new old tree* [*Function*]

(`subst` *new old tree*) substitutes *new* for all occurrences of *old* in *tree*, and returns the modified copy of *tree*. The original *tree* is unchanged, as `subst` recursively copies all of *tree* replacing elements `equal` to *old* as it goes.

For example:

```
(subst 'Tempest 'Hurricane
       '(Shakespeare wrote (The Hurricane)))
   => (Shakespeare wrote (The Tempest))
```

This function is not "destructive"; that is, it does not change the *car* or *cdr* of any already-existing list structure.

(`subst () () x`) is an idiom once frequently used to copy all the conses in a tree, but the `copytree` (page 123) function is more appropriate to the task.

`nsubst` *new old tree* [*Function*]

`nsubst` is a destructive version of `subst`. The list structure of *tree* is altered by replacing each occurrence of *old* with *new*. `equal` is used to decide whether a part of *tree* is the same as *old*.

`substq` *new old tree* [*Function*]

`substq` is just like `subst`, except that `eq`, rather than `equal`, is used to decide whether a part of *tree* is the same as *old*.

`nsubstq` *new old tree* [*Function*]

`nsubstq` is a destructive version of `substq`. `nsubstq` is just like `nsubst`, except that `eq`, rather than `equal`, is used to decide whether a part of *tree* is the same as *old*.

`sublis` *alist tree* [*Function*]

`sublis` makes substitutions for symbols in a tree (a structure of conses). The first argument to `sublis` is an association list. The *car* of each a-list entry should be a symbol. The second argument is the tree in which substitutions are to be made. `sublis` looks at all symbols in the tree; if a symbol appears as a key in the association list occurrences of it are replaced by the object it is associated with. The argument is not modified; new conses are created where necessary and only where necessary, so the newly created structure shares as much of its substructure as possible with the old. For example, if no substitutions are made, the result is `eq` to the old tree.

For example:

```
(sublis '((x . 100) (z . zprime))
        '(plus x (minus g z x p) 4))
  => (plus 100 (minus g zprime 100 p) 4)
```

`nsublis` *alist tree* [*Function*]

`nsublis` is like `sublis` but changes the original list structure instead of copying.

12.5. Using Lists as Sets

COMMON LISP includes functions which allow a list of items to be treated as a *set*. Some of the functions usefully allow the set to be ordered; others specifically support unordered sets. There are functions to add, remove, and search for items in a list, based on various criteria. There are also set union, intersection, and difference functions.

Many of the functions described here form a regular pattern according to two criteria:

- Whether elements are compared for equality by `equal`, `eq`, or some other specified predicate of one or two arguments.
- Whether the operation is destructive or not.

As a general rule, a function which uses `equal` is named by an English word; the corresponding function which uses an arbitrary two-argument predicate is named by some short prefix of that word; the function which uses `eq` is named by that prefix plus "`q`"; the function which uses a one-argument predicate is named by the prefix plus "`-if`"; and the function which takes a one-argument predicate but inverts its sense is named by the prefix plus "`-if-not`".

As another general rule, the destructive version of a function is named by prefixing "`n`" to the name of the version which is not destructive. An exception (for historical reasons) to this rule is the pair `delete` (page 98) and `remove` (page 91)/`list-remove` (page LIST-REMOVE-FUN).

`member` *item list* [*Function*]
`memq` *item list* [*Function*]
`mem` *predicate item list* [*Function*]
`mem-if` *predicate list* [*Function*]
`mem-if-not` *predicate list* [*Function*]

(`member` *item list*) returns ( ) if *item* is not one of the elements of *list*. Otherwise, it returns the tail of *list* beginning with the first occurrence of *item*. The comparison is made by `equal`. *list* is searched on the top level only. Because `member` returns ( ) if it doesn't find anything, and something non-( ) if it finds something, it is often used as a predicate.

For example:

```
(memq 'snerd '(a b c d)) => ()
(memq 'a '(g (a y) c a d e a f)) => (a d e a f)
```

Note that the value returned by `member` is `eq` to the portion of the list beginning with *a*. Thus `rplaca` on the result of `member` may be used, if you first check to make sure `member` did not return ( ).

`memq` is like `member`, except `eq` is used to compare the *item* to the list element, instead of `equal`.

`mem` is like `member`, except *predicate* is used to compare the *item* to the list element, instead of `equal`.

`mem-if` is like `member`, except that *predicate*, a function of one argument, is used to test elements of *list*.

`mem-if-not` is like `mem-if`, except that the sense of *predicate* is inverted; that is, a test succeeds if `predicate` returns ( ).

See also `position` (page 92) and `list-position` (page LIST-POSITION-FUN).

`tailp` *sublist list* [*Function*]

This predicate is true if *sublist* is a sublist of *list* (i.e. one of the conses that makes up *list*). Otherwise it is false. Another way to look at this is that `tailp` is true if (`nthcdr` *n list*) is *sublist*, for some value of *n*. See `buttail` (page 126).

`delete` *item list* `&optional` *n* [*Function*]
`delq` *item list* `&optional` *n* [*Function*]
`del` *predicate item list* `&optional` *n* [*Function*]
`del-if` *predicate list* `&optional` *n* [*Function*]
`del-if-not` *predicate list* `&optional` *n* [*Function*]

(`delete` *item list*) returns the *list* with all top-level occurrences of *item* removed. `equal` is used to compare *item* to elements of the list. The operation may be destructive; the argument *list* may be actually modified (`rplacd`'ed) when instances of *item* are spliced out. `delete` should be used for value, not for effect. That is, use

```
(setq a (delete x a))
```

rather than

```
(delete x a)
```

The latter is *not* equivalent when the first element of the value of a is x.

If the optional argument *n* is provided, it should be a non-negative integer; it specifies an upper limit on the number of deletions. (delete *item list n*) is like (delq *item list*) except only the first *n* instances of *item* are deleted. *n* is allowed to be zero, in which case no elements are deleted. If *n* is greater than the number of occurrences of *item* in the list, all occurrences of *item* in the list will be deleted.

For example:

```
(delete 'a '(b a c (a b) d a e)) => (b c (a b) d e)
(delete 'a '(b a c (a b) d a e) 1) => (b c (a b) d a e)
```

delq is like delete, except eq is used to compare the *item* to the list element, instead of equal.

del is like delete, except *predicate* is used to compare the *item* to the list element, instead of equal.

del-if is like delete, except that *predicate*, a function of one argument, is used to test elements of *list*.

del-if-not is like del-if, except that the sense of *predicate* is inverted; that is, a test succeeds if predicate returns ().

For non-destructive deletion, use remove (page 91) or list-remove (page LIST-REMOVE-FUN).

adjoin *item list* [*Function*]
adjq *item list* [*Function*]
adj *predicate item list* [*Function*]

adjoin is used to add an element to a set, provided that it is not already a member. equal is used to compare *item* to elements of *list*.

(adjoin *item list*)
means the same as
(if (member *item list*) *list* (cons *item list*))

adjq is like adjoin, except eq is used to compare the *item* to the list element, instead of equal.

adj is like adjoin, except *predicate* is used to compare the *item* to the list element, instead of equal.

union &rest *lists* [*Function*]
unionq &rest *lists* [*Function*]
unite *predicate* &rest *lists* [*Function*]

union takes any number of lists and returns a new list containing everything that is an element of any of the *lists*. If there is a duplication (as determined by equal) between two lists, only one of

the duplicate instances will be in the result. If any of the arguments has duplicate entries, the redundant entries may or may not appear in the result.

For example:

```
(union '(a b c) '(f a d)) => (a b c f d)
(union) => ()
```

If `union` is given no arguments, then `()` is returned, for `()` is the identity of the operation.

There is no guarantee that the order of elements in the result will reflect the ordering of the arguments in any particular way. The implementation is therefore free to use any of a variety of strategies.

`uniteq` is like `union`, except `eq` is used to compare elements of the *lists*, instead of `equal`.

`unite` is like `union`, except *predicate* is used to compare elements of the *lists*, instead of `equal`.

`nunion` `&rest` *lists* [*Function*]
`nunionq` `&rest` *lists* [*Function*]
`nunite` *predicate* `&rest` *lists* [*Function*]

`nunion` is the destructive version of `union`. *nunion* takes any number of lists and returns a new list containing everything that is an element of any of the *lists*. If there is a duplication (as determined by `equal`) between two lists, only one of the duplicate instances will be in the result. If any of the arguments has duplicate entries, the redundant entries may or may not appear in the result. Any of the argument lists may be cannibalized to construct the result.

If `nunion` is given no arguments, then `()` is returned, for `()` is the identity of the operation.

There is no guarantee that the order of elements in the result will reflect the ordering of the arguments in any particular way. The implementation is therefore free to use any of a variety of strategies.

`nuniteq` is like `nunion`, except `eq` is used to compare elements of the *lists*, instead of `equal`.

`nunite` is like `nunion`, except *predicate* is used to compare elements of the *lists*, instead of `equal`.

`intersection` *firstlist* `&rest` *otherlists* [*Function*]
`intersectq` *firstlist* `&rest` *otherlists* [*Function*]
`intersect` *predicate firstlist* `&rest` *otherlists* [*Function*]

`intersection` takes any number of lists and returns a new list containing everything that is an element of *firstlist* and also of the *otherlists*. If *firstlist* has duplicate entries, the redundant entries may or may not appear in the result.

For example:

```
(intersection '(a b c) '(f a d)) => (a)
```

Unfortunately, the identity for the `intersection` operation is the entire universe. Because there is no defined representation for that, `intersection` requires at least one argument.

There is no guarantee that the order of elements in the result will reflect the ordering of the arguments in any particular way. The implementation is therefore free to use any of a variety of strategies.

`intersectq` is like `intersection`, except `eq` is used to compare elements of the *lists*, instead of `equal`.

`intersect` is like `intersection`, except *predicate* is used to compare elements of the *lists*, instead of `equal`.

`nintersection` *firstlist* `&rest` *otherlists* [*Function*]
`nintersectq` *firstlist* `&rest` *otherlists* [*Function*]
`nintersect` *predicate firstlist* `&rest` *otherlists* [*Function*]

`nintersection` is the destructive version of `intersection`. Only *firstlist* may be destroyed, however. `nintersection` takes any number of lists and returns a new list containing everything that is an element of *firstlist* and also of the *otherlists*. If *firstlist* has duplicate entries, the redundant entries may or may not appear in the result.

Unfortunately, the identity for the `nintersection` operation is the entire universe. Because there is no defined representation for that, `nintersection` requires at least one argument.

There is no guarantee that the order of elements in the result will reflect the ordering of the arguments in any particular way. The implementation is therefore free to use any of a variety of strategies.

`nintersectq` is like `nintersection`, except `eq` is used to compare elements of the *lists*, instead of `equal`.

`nintersect` is like `nintersection`, except *predicate* is used to compare elements of the *lists*, instead of `equal`.

`setdifference` *list1 list2* [*Function*]
`setdiffq` *list1 list2* [*Function*]
`setdiff` *predicate list1 list2* [*Function*]

`setdifference` returns a list of elements of *list1* which do not appear in *list2*. This operation is not destructive. `equal` is used to compare elements of the lists.

`setdiffq` is like `setdifference`, except `eq` is used to compare elements of the lists, instead of `equal`.

`setdiff` is like `setdifference`, except *predicate* is used to compare elements of the lists, instead of `equal`.

`nsetdifference` *list1 list2* [*Function*]
`nsetdiffq` *list1 list2* [*Function*]
`nsetdiff` *predicate list1 list2* [*Function*]

`nsetdifference` is the destructive version of `setdifference`. `nsetdifference` returns a list of elements of *list1* which do not appear in *list2*. This operation may destroy *list1*. `equal` is used to compare elements of the lists.

`nsetdiffq` is like `nsetdifference`, except `eq` is used to compare elements of the lists, instead of `equal`.

`nsetdiff` is like `nsetdifference`, except *predicate* is used to compare elements of the lists, instead of `equal`.

`set-exclusive-or` *list1 list2* [*Function*]
`setxorq` *list1 list2* [*Function*]
`setxor` *predicate list1 list2* [*Function*]

`set-exclusive-or` returns a list of elements which appear in exactly one of *list1* and *list2*. This operation is not destructive. `equal` is used to compare elements of the lists.

`setxorq` is like `set-exclusive-or`, except `eq` is used to compare elements of the lists, instead of `equal`.

`setxor` is like `set-exclusive-or`, except *predicate* is used to compare elements of the lists, instead of `equal`.

`nset-exclusive-or` *list1 list2* [*Function*]
`nsetxorq` *list1 list2* [*Function*]
`nsetxor` *predicate list1 list2* [*Function*]

`nset-exclusive-or` is the destructive version of `set-exclusive-or`. `nset-exclusive-or` returns a list of elements which appear in exactly one of *list1* and *list2*. Both lists may be destroyed in producing the result. `equal` is used to compare elements of the lists.

`nsetxorq` is like `nset-exclusive-or`, except `eq` is used to compare elements of the lists, instead of `equal`.

`nsetxor` is like `nset-exclusive-or`, except *predicate* is used to compare elements of the lists, instead of `equal`.

12.6. Association Lists

An *association list*, or *a-list*, is a data structure used very frequently in LISP. An a-list is a list of pairs (conses); each pair is an association. The *car* of a pair is called the *key*, and the *cdr* is called the *datum*.

An advantage of the a-list representation is that an a-list can be incrementally augmented simply by adding new entries to the front. Moreover, because the searching functions such as `assoc` search the a-list in order, new entries can "shadow" old entries. If an a-list is viewed as a mapping from keys to data, then the mapping can be not only augmented but also altered in a non-destructive manner by adding new entries to the front of the a-list.

Sometimes an a-list represents a bijective mapping, and it is desirable to retrieve a key given a datum. For this purpose "reverse" forms of the a-list functions are provided.

It is permissible to let ( ) be an element of an a-list in place of a pair.

`acons` *key datum a-list* [*Function*]

`acons` constructs a new association list by adding the pair (*key* . *datum*) to the old *a-list*.

```
(acons x y a) <=> (cons (cons x y) a)
```

`pairlis` *keys data* `&optional` *a-list* [*Function*]

`pairlis` takes two lists and makes an association list which associates elements of the first list to corresponding elements of the second list. It is an error if the two lists *keys* and *data* are not of the same length. If the optional argument *a-list* is provided, then the new pairs are added to the front of it.

For example:

```
(pairlis '(beef clams kitty) '(roast fried yu-shiang))
   => ((beef . roast) (clams . fried) (kitty . yu-shiang))
(pairlis '(one two) '(1 2) '((three . 3) (four . 19)))
   => ((one . 1) (two . 2) (three . 3) (four . 19))
```

The remaining association-list functions form a regular collection according to three independent criteria:

- The type of operation is indicated by a prefix to the function name:

no prefix	Search, returning an association pair.
`mem`	Search, returning a tail of the a-list.
`pos`	Search, returning a numerical index into the a-list.
`del`	Destructive deletion.

The prefixes indicate that the operations are related to the functions `member` (page 130), `position` (page 92), and `delete` (page 130).

- If the function treats the a-list normally (the *car* of each association pair is treated as the key), then no infix is written. If the function treats the a-list as a reverse mapping (the *cdr* of each association pair is treated as the key), then the letter "`r`" is written.

- The suffix names the a-list operation and indicates the testing criterion:

`assoc`	Compare against an item using `equal`.

`assq`	Compare against an item using `eq`.
`ass`	Compare against an item using a user-specified predicate.
`ass-if`	Use a single-argument user-specified predicate.
`ass-if-not`	Invert a single-argument user-specified predicate.

Thus, for example, the function `posrassq` would perform a search, returning the numerical position, treating the a-list in reverse form, and using `eq` to test the keys.

`assoc` *item a-list* [*Function*]
`assq` *item a-list* [*Function*]
`ass` *predicate item a-list* [*Function*]
`ass-if` *predicate a-list* [*Function*]
`ass-if-not` *predicate a-list* [*Function*]

`(assoc` *item alist*`)` looks up *item* in the association list *a-list*. The value is the first pair in the a-list whose `car` is `equal` to *x*, or `()` if there is none such.

For example:

```
(assoc 'r '((a . b) (c . d) (r . x) (s . y) (r . z)))
        => (r . x)
(assoc 'goo '((foo . bar) (zoo . goo))) => ()
(assoc '2 '((1 a b c) (2 b c d) (-7 x y z))) => (2 b c d)
```

It is possible to `rplacd` the result of `assoc` *provided* that it is not `()`, if your intention is to "update" the "table" that was `assoc`'s second argument. (However, it is often better to update an a-list by adding new pairs to the front, rather than altering old pairs.)

For example:

```
(setq values '((x . 100) (y . 200) (z . 50)))
(assoc 'y values) => (y . 200)
(rplacd (assoc 'y values) 201)
(assoc 'y values) => (y . 201) now
```

A typical trick is to say `(cdr (assoc x y))`. Because the *cdr* of `()` is guaranteed to be `()`, this yields `()` if no pair is found *or* if a pair is found whose *cdr* is `()`. This is useful if `()` serves its usual role as a "default value".

`assq` is like `assoc`, except `eq` is used to compare the *item* to each key, instead of `equal`.

`ass` is like `assoc`, except *predicate* is used to compare the *item* to each key, instead of `equal`.

`ass-if` is like `assoc`, except that *predicate*, a function of one argument, is used to test keys of *a-list*.

`ass-if-not` is like `ass-if`, except that the sense of *predicate* is inverted; that is, a test succeeds if `predicate` returns `()`.

`rassoc` *item a-list* [*Function*]
`rassq` *item a-list* [*Function*]
`rass` *predicate item a-list* [*Function*]
`rass-if` *predicate a-list* [*Function*]
`rass-if-not` *predicate a-list* [*Function*]

`rassoc` is the reverse form of `assoc`; it compares *item* to the *cdr* of each successive pair in *a-list*, rather than to the *car*. Similarly, `rassq` is the reverse form of `assq`, and so on.

For example:

```
(rassoc 'a '((a . b) (b . c) (c . a) (z . a))) => (c . a)
```

`memassoc` *item a-list* [*Function*]
`memassq` *item a-list* [*Function*]
`memass` *predicate item a-list* [*Function*]
`memass-if` *predicate a-list* [*Function*]
`memass-if-not` *predicate a-list* [*Function*]

`memassoc` is a synthesis of `assoc` (page 136) and `member` (page 130).

(`memassoc` *item alist*) looks up *item* in the association list *a-list*. The value is the portion of the a-list whose first pair is the first pair in *a-list* whose `car` is `equal` to *x*, or ( ) if there is none such. Thus `memassoc` performs its search like `assoc`, but returns a value like `member`.

For example:

```
(memassoc 'r '((a . b) (c . d) (r . x) (s . y) (r . z)))
   => ((r . x) (s . y) (r . z))
(memassoc 'goo '((foo . bar) (zoo . goo))) => ()
(memassoc '2 '((1 a b c) (2 b c d) (-7 x y z)))
   => ((2 b c d) (-7 x y z))
```

`memassq` is like `memassoc`, except `eq` is used to compare the *item* to each key, instead of `equal`.

`memass` is like `memassoc`, except *predicate* is used to compare the *item* to each key, instead of `equal`.

`memass-if` is like `memassoc`, except that *predicate*, a function of one argument, is used to test keys of *a-list*.

`memass-if-not` is like `memass-if`, except that the sense of *predicate* is inverted; that is, a test succeeds if `predicate` returns `()`.

`memrassoc` *item a-list* [*Function*]
`memrassq` *item a-list* [*Function*]
`memrass` *predicate item a-list* [*Function*]
`memrass-if` *predicate a-list* [*Function*]
`memrass-if-not` *predicate a-list* [*Function*]

`memrassoc` is the reverse form of `memassoc`; it compares *item* to the *cdr* of each successive pair in *a-list*, rather than to the *car*. Similarly, `memrassq` is the reverse form of `memassq`, and so on.

For example:

```
(memrassoc 'a '((a . b) (b . c) (c . a) (z . a) (p . q)))
   => ((c . a) (z . a) (p . q))
```

`posassoc` *item a-list* [*Function*]
`posassq` *item a-list* [*Function*]
`posass` *predicate item a-list* [*Function*]
`posass-if` *predicate a-list* [*Function*]
`posass-if-not` *predicate a-list* [*Function*]

`posassoc` is a synthesis of `assoc` (page 136) and `position` (page 92).

(`posassoc` *item alist*) looks up *item* in the association list *a-list*. The value is the zero-origin numerical position of the first pair in the a-list whose `car` is `equal` to *x*, or `()` if there is none such.

For example:

```
(posassoc 'r '((a . b) (c . d) (r . x) (s . y) (r . z)))
   => 2
(posassoc 'goo '((foo . bar) (zoo . goo))) => ()
(posassoc '2 '((1 a b c) (2 b c d) (-7 x y z))) => 1
```

`posassq` is like `posassoc`, except `eq` is used to compare the *item* to each key, instead of `equal`.

`posass` is like `posassoc`, except *predicate* is used to compare the *item* to each key, instead of `equal`.

`posass-if` is like `posassoc`, except that *predicate*, a function of one argument, is used to test keys of *a-list*.

`posass-if-not` is like `posass-if`, except that the sense of *predicate* is inverted; that is, a test succeeds if `predicate` returns `()`.

`posrassoc` *item a-list* [*Function*]
`posrassq` *item a-list* [*Function*]
`posrass` *predicate item a-list* [*Function*]
`posrass-if` *predicate a-list* [*Function*]
`posrass-if-not` *predicate a-list* [*Function*]

`posrassoc` is the reverse form of `posassoc`; it compares *item* to the *cdr* of each successive pair in *a-list*, rather than to the *car*. Similarly, `posrassq` is the reverse form of `posassq`, and so on.

For example:

```
(posrassoc 'a '((a . b) (b . c) (c . a) (z . a))) => 2
```

`delassoc` *item a-list* `&optional` *n* [*Function*]
`delassq` *item a-list* `&optional` *n* [*Function*]
`delass` *predicate item a-list* `&optional` *n* [*Function*]
`delass-if` *predicate a-list* `&optional` *n* [*Function*]
`delass-if-not` *predicate a-list* `&optional` *n* [*Function*]

`delassoc` is a synthesis of `assoc` (page 136) and `delete` (page 130).

(`delassoc` *item alist*) looks up *item* in the association list *a-list*. Any and all pairs to whose key *item* is `equal` are destructively spliced out of *a-list*. The value is the modified *a-list*.

For example:

```
(delassoc 'r '((a . b) (c . d) (r . x) (s . y) (r . z)))
   => ((a . b) (c . d) (s . y))

(delassoc 'goo '((foo . bar) (zoo . goo)))
   => ((foo . bar) (zoo . goo))    (The argument was not modified.)

(delassoc '2 '((1 a b c) (2 b c d) (-7 x y z)))
   => ((1 a b c) (-7 x y z))
```

If the optional argument *n* is provided, it should be a non-negative integer; it specifies an upper bound on the number of pairs to be removed. (In this `delassoc` behaves exactly like `delete`.)

`delassq` is like `delassoc`, except `eq` is used to compare the *item* to each key, instead of `equal`.

`delass` is like `delassoc`, except *predicate* is used to compare the *item* to each key, instead of `equal`.

`delass-if` is like `delassoc`, except that *predicate*, a function of one argument, is used to test keys of *a-list*.

`delass-if-not` is like `delass-if`, except that the sense of *predicate* is inverted; that is, a test succeeds if `predicate` returns `()`.

`delrassoc` *item a-list* `&optional` *n* [*Function*]
`delrassq` *item a-list* `&optional` *n* [*Function*]
`delrass` *predicate item a-list* `&optional` *n* [*Function*]
`delrass-if` *predicate a-list* `&optional` *n* [*Function*]
`delrass-if-not` *predicate a-list* `&optional` *n* [*Function*]

`delrassoc` is the reverse form of `delassoc`; it compares *item* to the *cdr* of each successive pair in *a-list*, rather than to the *car*. Similarly, `delrassq` is the reverse form of `delassq`, and so on.

For example:

```
(delrassoc 'a '((a . b) (b . c) (c . a) (z . a)))
   => ((a . b) (b . c))
```

Compatibility note: The functions `sassoc` and `sassq` have been omitted. They were useless hangovers from LISP 1.5 days.

12.7. Hash Tables

A hash table is a LISP object that works something like a property list and something like an association list. Each hash table has a set of *entries*, each of which associates a particular *key* with a particular *value*. The basic functions that deal with hash tables can create entries, delete entries, and find the value that is associated with a given key. Finding the value is very fast even if there are many entries, because hashing is used; this is an important advantage of hash tables over property lists.

A given hash table can only associate one *value* with a given *key*; if you try to add a second *value* it will replace the first. Also, adding a value to a hash table is a destructive operation; the hash table is modified. By contrast, association lists can be augmented non-destructively.

Hash tables come in two kinds, the difference being whether the keys are compared with `eq` or with `equal`. In other words, there are hash tables which hash on Lisp *objects* (using `eq`) and there are hash tables which hash on abstract *S-expressions* (using `equal`).

Hash tables of the first kind are created with the function `make-hash-table`, which takes various options. New entries are added to hash tables with the `puthash` function. To look up a key and find the associated value, use `gethash`; to remove an entry, use `remhash`. Here is a simple example.

```
(setq a (make-hash-table))
(puthash 'color 'brown a)
(puthash 'name 'fred a)
(gethash 'color a) => brown
(gethash 'name a) => fred
(gethash 'pointy a) => ()
```

In this example, the symbols `color` and `name` are being used as keys, and the symbols `brown` and `fred` are being used as the associated values. The hash table has two items in it, one of which associates from `color` to `brown`, and the other of which associates from `name` to `fred`.

Keys do not have to be symbols; they can be any LISP object. Likewise values can be any LISP object. Hash tables are properly interfaced to the relocating garbage collector so that garbage collection will have no perceptible effect on the functionality of hash tables.

When a hash table is first created, it has a *size*, which is the maximum number of entries it can hold. Usually the actual capacity of the table is somewhat less, since the hashing is not perfectly collision-free. With the maximum possible bad luck, the capacity could be very much less, but this rarely happens. If so many entries are added that the capacity is exceeded, the hash table will automatically grow, and the entries will be *rehashed* (new hash values will be recomputed, and everything will be rearranged so that the fast hash lookup still works). This is transparent to the caller; it all happens automatically.

> **Compatibility note:** This hash table facility is compatible with Lisp Machine LISP. It is similar to the hasharray facility of INTERLISP, and some of the function names are the same. However, it is *not* compatible with INTERLISP. The exact details and the order of arguments are designed to be consistent with the rest of MACLISP rather than with INTERLISP. For instance, the order of arguments to `maphash` is different, there is no "system hash table", and there is not the INTERLISP restriction that keys and values may not be `()`. Note, however, that the order of arguments to `gethash`, `puthash`, and `remhash` is

not consistent with `get`, `putprop`, and `remprop`, either. This is an unfortunate result of the haphazard historical development of Lisp.

12.7.1. Hash Table Functions

This section documents the functions for hash tables, which use *objects* as keys and associate other objects with them.

`make-eq-hash-table &rest` *options* [*Function*]
`make-eql-hash-table &rest` *options* [*Function*]
`make-equal-hash-table &rest` *options* [*Function*]

Calling any of these creates a new hash table; depending on which one is used, the resulting table treats keys as equal if they are `eq`, `eql`, or `equal`, respectively.

The number of arguments should be even. Each pair of arguments specifies an option; the first is a keyword symbol, and the second a value for that option. Valid option keywords are:

`size` Set the initial size of the hash table, in entries, as a fixnum. The default is 64. The actual size is rounded up from the size you specify to the next "good" size. You won't necessarily be able to store this many entries into the table before it overflows and becomes bigger; but except in the case of extreme bad luck you will be able to store almost this many.

`rehash-size` Specifies how much to increase the size of the hash table when it becomes full. This can be an integer greater than zero, which is the number of entries to add, or it can be a floating-point number greater than one, which is the ratio of the new size to the old size. The default is `1.3`, which causes the table to be made 30% bigger each time it has to grow.

`rehash-threshold`
Specifies how full the hash table can get before it must grow. This can be an integer greater than zero and less than the rehash-size (in which case it will be scaled whenever the table is grown), or it can be a floating-point number between zero and one. The default is `0.8`, which means the table is enlarged when it becomes over 80% full.

For example:

```
(make-hash-table 'rehash-size 1.5
                 'size (* number-of-widgets 43))
```

`gethash` *key hash-table* `&optional` *default* [*Function*]

Find the entry in *hash-table* whose key is *key*, and return the associated value. If there is no such entry, return *default*, which is `( )` if not specified.

`gethash` actually returns two values, the second being a predicate value that is true if an entry was found, and false if no entry was found.

`puthash` *key value hash-table* [*Function*]

Create an entry in *hash-table* associating *key* to *value*; if there is already an entry for *key*, then replace the value of that entry with *value*. Returns *value*.

`remhash` *key hash-table* [*Function*]

Remove any entry for *key* in *hash-table*. This is a predicate that is true if there was an entry or false if there was not.

`maphash` *function hash-table* [*Function*]

For each entry in *hash-table*, call *function* on two arguments: the key of the entry and the value of the entry. If entries are added to or deleted from the hash table while a `maphash` is in progress, the results are unpredictable. `maphash` returns `()`.

`clrhash` *hash-table* [*Function*]

Remove all the entries from *hash-table*. Returns the hash table itself.

12.7.2. Primitive Hash Function

`sxhash` *S-expression* [*Function*]

`sxhash` computes a hash code of an S-expression, and returns it as a non-negative fixnum. A property of `sxhash` is that `(equal x y)` implies `(= (sxhash x) (sxhash y))`.

Chapter 13

Symbols

A LISP symbol is a data object which has three user-visible components:

- The *property list* is a list which effectively provides each symbol with many modifiable named components.
- The *print name* must be a string, which is the sequence of characters used to identify the symbol. Symbols are of great use because a symbol can be located given its name (typed, say, on a keyboard). It is ordinarily not permitted to alter a symbol's print name.
- The *package cell* must refer to a package object. A package is a data structure used to locate a symbol given its name. A symbol is uniquely identified by its name only when considered relative to a package. A symbol may be in many packages, but it can be *owned* by at most one package. The package cell points to the owner, if any.

A symbol may actually have other components as well for use by the implementation. One of the more important uses of symbols is as names for program variables; it is frequently desirable for the implementor to use certain components of a symbol to implement the semantics of variables. However, there are several possible implementation strategies, and so such possible components are not described here.

The three components named above and the functions related to them are described more individually and in more detail in the following sections.

13.1. The Property List

Since its inception, LISP has associated with each symbol a kind of tabular data structure called a *property list* (*plist* for short). A property list contains zero or more entries; each entry associates from a keyword symbol (called the *indicator*) to a Lisp object (called the *value* or, sometimes, the *property*). There are no duplications among the indicators; a property-list may only have one property at a time with a given name. In this way, given a symbol and an indicator (another symbol), an associated value can be retrieved.

A property list is very similar in purpose to an association list. The difference is that a property list is an object with a unique identity; the operations for adding and removing property-list entries are destructive operations which alter the property-list rather than making a new one. Association lists, on the other hand,

are normally augmented non-destructively (without side effects), by adding new entries to the front (see `acons` (page 135) and `pairlis` (page 135)).

A property list is implemented as a memory cell (the property list cell) in a symbol containing a list with an even number (possibly zero) of elements. Each pair of elements constitutes an entry; the first item is the indicator and the second is the value. Because property-list functions are given the symbol and not the list itself, modifications to the property list can be recorded by storing back into the property-list cell of the symbol.

When a symbol is created, its property list is initially empty. Properties are created by `putprop` (page 113) and related functions.

COMMON LISP does not use a symbol's property list as extensively as earlier LISP implementations did. Less-used data, such as compiler, debugging, and documentation information, is kept on property lists in COMMON LISP.

Compatibility note: In older Lisp implementations, the print name, value, and function definition of a symbol were kept on its property list. The value cell was introduced into MACLISP and INTERLISP to speed up access to variables; similarly for the print-name cell and function cell (MACLISP does not use a function cell). Recent LISP implementations such as SPICE LISP, Lisp Machine LISP, and NIL have introduced all of these cells plus the package cell. None of the MACLISP system property names (`expr`, `fexpr`, `macro`, `array`, `subr`, `lsubr`, `fsubr`, and in former times `value` and `pname`) exist in COMMON LISP.

Compatibility note: In COMMON LISP, the notion of "disembodied property list" introduced in MACLISP is eliminated. It tended to be used for rather kludgy things, and in Lisp Machine LISP is often associated with the use of locatives (to make it "off by one" for searching alternating keyword lists). In COMMON LISP special `setf`-like property list functions are introduced: `getf` (page GETF-FUN), `putpropf` (page PUTPROPF-FUN), and `rempropf` (page REMPROPF-FUN).

`get` *symbol indicator* `&optional` *default* [*Function*]

get searches the property list of *symbol* for an indicator `eq` to *indicator*. If one is found, then the corresponding value is returned; otherwise *default* is returned. If *default* is not specified, then `()` is used for *default*. Note that there is no way to distinguish an absent property from one whose value is *default*.

Suppose that the property list of `foo` is `(bar t baz 3 hunoz "Huh?")`. Then, for example:

```
(get 'foo 'baz) => 3
(get 'foo 'hunoz) => "Huh?"
(get 'foo 'zoo) => ()
        ; a isn't even part of the (disembodied) property list
```

`getl` *symbol indicator-list* [*Function*]

`getl` is like `get`, except that the second argument is a list of indicators. `getl` searches the property list of *symbol* for any of the indicators in *indicator-list*, until it finds a property whose indicator is one of the elements of *indicator-list*.

`getl` returns that tail of the property list which begins with the first such property found. So the *car* of the returned list is an indicator, and the *cadr* is the property value. If none of the indicators on *indicator-list* are on the property list, `getl` returns `()`.

For example:

If the property list of `foo` were
```
(bar (1 2 3) baz (3 2 1) color blue height six-two)
```
then
```
(getl 'foo '(baz height))
  => (baz (3 2 1) color blue height six-two)
```

When more than one of the indicators in *indicator-list* is present in *symbol*, which one `getl` returns depends on the order of the properties. `getl` is the only function that depends on that order. The order in which properties appear on a property list is implementation-dependent. Programs should avoid examining the *cddr* of a result returned by `getl`.

`putprop` *symbol value indicator* [*Function*]

This causes *symbol* to have a property whose indicator is *indicator* and whose value is *value*. If the property list already already had a property with an indicator `eq` to *indicator*, then the value previously associated with that indicator is removed from the property list and replaced by *value*. The property list is destructively altered by using side effects. After a `putprop` is done, (`get` *symbol indicator*) will return *value*. `putprop` returns the new *value*.

For example:
```
(putprop 'Nixon 'not 'crook) => not
(get 'Nixon 'crook) => not
```

`defprop` *symbol value indicator* [*Special form*]

`defprop` is a form of `putprop` with unevaluated arguments, which is sometimes more convenient for typing.

For example:
```
(defprop foo bar next-to) <=> (putprop 'foo 'bar 'next-to)
```

Often it is convenient to represent a data base by using property lists, and to initialize it by evaluating a file of `defprop` forms.

For example:
```
(defprop and 0 pdp-8-opcode)
(defprop tad 1 pdp-8-opcode)
(defprop dca 2 pdp-8-opcode)
(defprop isz 3 pdp-8-opcode)
(defprop jms 4 pdp-8-opcode)
(defprop jmp 5 pdp-8-opcode)
(defprop iot 6 pdp-8-opcode)
```

Normally it doesn't make sense to use a disembodied property list rather than a symbol as the *symbol* argument.

`remprop` *symbol indicator* [*Function*]

This removes from *symbol* the property with an indicator `eq` to *indicator*, by splicing it out of the property list. It returns that portion of the property list of which value of the former *indicator*-property was the `car`. `car` of what `remprop` returns is what `get` would have returned with the same arguments.

For example:

If the property list of `foo` was
```
(color blue height 6.3 near-to bar)
```
then
```
(remprop 'foo 'height) => (6.3 near-to bar)
```
and `foo`'s property list would have been altered to be
```
(color blue near-to bar)
```

If *symbol* has no *indicator*-property, then `remprop` has no side-effect and returns `()`.

`plist` *symbol* [*Function*]

This returns the list which contains the property pairs of *symbol*. For a disembodied property list, this simply performs a `cdr` operation; for a symbol, the contents of the property list cell are extracted and returned.

Note that using `get` on the result of `plist` does *not* work. One must give the symbol itself to `get`.

13.2. The Print Name

Every symbol has an associated string called the *print-name*, or *pname* for short. This string is used as the external representation of the symbol: if the characters in the string are typed in to `read` (with suitable escape conventions for certain characters), it is interpreted as a reference to that symbol (if it is interned); and if the symbol is printed, `print` types out the print-name. For more information, see the section on the *reader* (see page READER) and *printer* (see page PRINTER).

`get-pname` *sym* [*Function*]

This returns the print-name of the symbol *sym*.

For example:
```
(get-pname 'XYZ) => "XYZ"
```

It is an extremely bad idea to modify a string being used as the print name of a symbol. Such a modification may confuse the function `read` (page 197) and the package system tremendously.

`samepnamep` *sym1 sym2* [*Function*]

This predicate is true if the two symbols *sym1* and *sym2* have `equal` print-names; that is, if their printed representation is the same. Upper and lower case letters are considered to be different.

Compatibility note: In Lisp Machine Lisp, `samepnamep` normally considers upper and lower case to be the same. However, in MacLisp, which originated this function, the cases are distinguished; Lisp Machine Lisp

introduced the incompatibility. COMMON LISP is compatible with MACLISP here.

If either or both of the arguments is a string instead of a symbol, then that string is used in place of the print-name. `samepnamep` is useful for determining if two symbols would be the same except that they are not in the same package.

For example:

```
(samepnamep 'xyz (maknam '(x y z)) is true
(samepnamep 'xyz (maknam '(w x y)) is false
```

13.3. Creating Symbols

Symbols can be used in two rather different ways. An *interned* symbol is one which is indexed by its print-name in a catalog called a *package*. Every time anyone asks for a symbol with that print-name, he gets the same (`eq`) symbol. Every time input is read with the function `read` (page 197), and that print-name appears, it is read as the same symbol. This property of symbols makes them appropriate to use as names for things and as hooks on which to hang permanent data objects (using the property list, for example; it is no accident that symbols are both the only LISP objects which are cataloged and the only LISP objects which have property lists).

Interned symbols are normally created automatically; the first time someone (such as the function `read`) asks the package system for a symbol with a given print-name, that symbol is automatically created. The function to use to ask for an interned symbol is `intern` (page INTERN-FUN), or one of the functions related to `intern`.

Although interned symbols are the most commonly used, they will not be discussed further here. For more information, turn to the chapter on packages.

An *uninterned* symbol is a symbol used simply as a data object, with no special cataloging (it belongs to no particular package). An uninterned symbol prints in the same way as an interned symbol with the same print-name, but cannot be read back in. The following are some functions for creating uninterned symbols.

`make-symbol` *pname* [*Function*]

(`make-symbol` *pname*) creates a new uninterned symbol, whose print-name is the string *pname*. The value and function bindings will be unbound and the property list will be empty.

The string actually installed in the symbol's print-name component may be the given string *pname* or may be a copy of it, at the implementation's discretion. The user should not assume that (`get-pname (make-symbol x)`) is `eq` to `x`, but also should not alter a string once it has been given as an argument to `make-symbol`.

Implementation note: An implementation might choose, for example, to copy the string to some read-only area, in the expectation that it will never be altered.

Compatibility note: Lisp Machine LISP uses the second argument for an odd flag related to areas. It is unclear what NIL does about this.

`copysymbol` *sym* `&optional` *copy-props* [*Function*]

This returns a new uninterned symbol with the same print-name as *sym*. If *copy-props* is non-( ), then the initial value and function-definition of the new symbol will be the same as those of *sym*, and the property list of the new symbol will be a copy of *sym*'s. If *copy-props* is ( ) (the default), then the new symbol will be unbound and undefined, and its property list will be empty.

`gensym` `&optional` *x* [*Function*]

`gensym` invents a print-name, and creates a new symbol with that print-name. It returns the new, uninterned symbol.

The invented print-name consists of a prefix (which defaults to "G"), followed by the decimal representation of a number. The number is increased by one every time `gensym` is called.

If the argument *x* is present and is an integer, then *x* must be non-negative, and the internal counter is set to x for future use; otherwise the internal counter is incremented. If *x* is a string, then that string is made the default prefix for this and future calls to `gensym`. After handling the argument, `gensym` creates a symbol as it would with no argument.

For example:

```
(gensym) => G7
(gensym "FOO-") => FOO-8
(gensym 32) => FOO-32
(gensym) => FOO-33
(gensym "GARBAGE") => GARBAGE-34
```

who provides the hyphen?

`gensym` is usually used to create a symbol which should not normally be seen by the user, and whose print-name is unimportant, except to allow easy distinction by eye between two such symbols. The optional argument is rarely supplied. The name comes from "generate symbol", and the symbols produced by it are often called "gensyms".

If it is crucial that no two generated symbols have the same print name (rather than merely being distinct data structures), or if it is desirable for the generated symbols to be interned, then the function `gentemp` (page GENTEMP-FUN) may be more appropriate to use.

`symbol-package` *sym* [*Function*]

Given a symbol *sym*, `symbol-package` returns the contents of the package cell of that symbol.

Chapter 14

Numbers

COMMON LISP provides several different representations for numbers. These representations may be divided into four categories: integers, ratios, floating-point numbers, and complex numbers. Many numeric functions will accept any kind of number; they are *generic*. Those functions which accept only certain kinds of numbers are so documented below.

In general, numbers in COMMON LISP are not true objects; `eq` cannot be counted upon to operate on them reliably. In particular, it is possible that the expression

```
(let ((x z) (y z)) (eq x y))
```

may be false rather than true, if the value of `z` is a number.

> Rationale: This odd breakdown of `eq` in the case of numbers allows the implementor enough design freedom to produce exceptionally efficient numerical code on conventional architectures. MACLISP requires this freedom, for example, in order to produce compiled numerical code equal in speed to FORTRAN. If not for this freedom, then at least for the sake of compatibility, COMMON LISP makes this same restriction.

If two objects are to be compared for "identity", but either might be a number, then the predicate `eql` (page 39) is probably appropriate; if both objects are known to be numbers, then `=` (page 118) may be preferable.

As a rule, computations with floating-point numbers are only approximate. The *precision* of a floating-point number is not necessarily correlated at all with the *accuracy* of that number. The precision refers to the number of bits retained in the representation. When an operation combines a short floating-point number with a long one, the result will be a long floating-point number. This rule is made to ensure that as much accuracy as possible is preserved; however, it is by no means a guarantee. COMMON LISP numerical routines do assume, however, that the accuracy of an argument does not exceed its precision. Therefore when two small floating-point numbers are combined, the result will always be a small floating-point number. This assumption can be overridden by first explicitly converting a small floating-point number to a larger representation. (COMMON LISP never converts automatically from a larger size to a smaller one in an effort to save space.)

Rational computations cannot overflow in the usual sense (though of course there may not be enough storage to represent one), as integers and ratios may in principle be of any magnitude. Floating-point computations may get exponent overflow or underflow, in which case an error is signalled.

14.1. Predicates on Numbers

`zerop` *number* [*Function*]

This predicate is true if *number* is zero (either the integer zero, a floating-point zero, or a complex zero), and is false otherwise. It is an error if the argument *number* is not a number.

`plusp` *number* [*Function*]

This predicate is true if *number* is strictly greater than zero, and is false otherwise. It is an error if the argument *number* is not a non-complex number.

`minusp` *number* [*Function*]

This predicate is true if *number* is strictly less than zero; otherwise ( ) is returned. It is an error if the argument *number* is not a non-complex number.

`oddp` *integer* [*Function*]

This predicate is true if the argument *integer* is odd (not divisible by two), and otherwise is false. It is an error if the argument is not an integer.

`evenp` *integer* [*Function*]

This predicate is true if the argument *integer* is even (divisible by two), and otherwise is false. It is an error if the argument is not an integer.

See also the data-type predicates `integerp` (page 37), `rationalp` (page 37) `floatp` (page 38), `complexp` (page COMPLEXP-FUN), and `numberp` (page 37).

14.2. Comparisons on Numbers

All of the functions in this section require that their arguments be numbers, and signal an error if given a non-number. They work on all types of numbers, automatically performing any required coercions.

`=` *number* `&rest` *more-numbers* [*Function*]
`/=` *number* `&rest` *more-numbers* [*Function*]
`<` *number* `&rest` *more-numbers* [*Function*]
`>` *number* `&rest` *more-numbers* [*Function*]
`<=` *number* `&rest` *more-numbers* [*Function*]
`>=` *number* `&rest` *more-numbers* [*Function*]

These functions each take one or more arguments. If the sequence of arguments satisfies a certain condition:

`=` all the same

`/=`	all different
`<`	monotonically increasing
`>`	monotonically decreasing
`<=`	monotonically nondecreasing
`>=`	monotonically nonincreasing

then the predicate is true, and otherwise is false. Complex numbers may be compared using = and /=, but the others require non-complex arguments.

For example:

```
(= 3 3) is true                    (/= 3 3) is false
(= 3 5) is false                   (/= 3 5) is true
(= 3 3 3 3) is true                (/= 3 3 3 3) is false
(= 3 3 5 3) is false               (/= 3 3 5 3) is false
(= 3 6 5 2) is false               (/= 3 6 5 2) is true
(< 3 5) is true                    (<= 3 5) is true
(< 3 -5) is false                  (<= 3 -5) is false
(< 3 3) is false                   (<= 3 3) is true
(< 0 3 4 6 7) is true              (<= 0 3 4 6 7) is true
(< 0 3 4 4 6) is false             (<= 0 3 4 4 6) is true
(> 4 3) is true                    (>= 4 3) is true
(> 4 3 2 1 0) is true              (>= 4 3 2 1 0) is true
(> 4 3 3 2 0) is false             (>= 4 3 3 2 0) is true
(> 4 3 1 2 0) is false             (>= 4 3 1 2 0) is false
```

With two arguments, these functions perform the usual arithmetic comparison tests. With three or more arguments, they are useful for range checks.

For example:

```
(<= 0 x 9)                  ;true iff x is between 0 and 9, inclusive
(< 0.0 x 1.0)               ;true iff x is between 0.0 and 1.0, exclusive
(< -1 j (length s))         ;true iff j is a valid index for s
(<= 0 j k (- (length s) 1))     ;true iff j and k are each valid
                            ;    indices for s and also j≤k
```

For two non-complex arguments *x* and *y*, the law of trichotomy holds. Exactly one of `(= x y)`, `(< x y)`, and `(> x y)` will be true. Also:

```
(/= x y) <=> (not (= x y)) <=> (or (< x y) (> x y))
(<= x y) <=> (not (> x y)) <=> (or (< x y) (= x y))
(>= x y) <=> (not (< x y)) <=> (or (< x y) (= x y))
```

These relationships do *not* generalize to more or fewer than two arguments.

Rationale: The "unequality" relation is called "/=" rather than "<>" (the name used in PASCAL) for two reasons. First, /= of more than two arguments is not the same as the or of < and > of those same arguments. Second, unequality is meaningful for complex numbers even though < and > are not. For both reasons it would be misleading to associate unequality with the names of < and >.

Compatibility note: In COMMON LISP, the comparison operations perform "mixed-mode" comparisons: (= 3 3.0) is true. In MACLISP, there must be exactly two arguments, and they must be either both fixnums or both floating-point numbers.

How about "NOT=" ?

`max` *number* `&rest` *more-numbers* [*Function*]

The arguments may be any non-complex numbers. `max` returns the argument which is greatest (closest to positive infinity).

For example:

```
(max 1 3 2 -7) => 3
(max -2 3 0 7) => 7
(max 3) => 3
(max 3.0 7 1) => 7 or 7.0
```

If the arguments are a mixture of integers and floating-point numbers, and the largest is a rational, then the implementation is free to produce either that rational or its floating-point approximation.

`min` *number* `&rest` *more-numbers* [*Function*]

The arguments may be any non-complex numbers. `min` returns the argument which is least (closest to negative infinity).

For example:

```
(max 1 3 2 -7) => -7
(max -2 3 0 7) => -2
(min 3) => 3
(min 3.0 7 1) => 1 or 1.0
```

If the arguments are a mixture of rationals and floating-point numbers, and the smallest is a rational, then the implementation is free to produce either that rational or its floating-point approximation.

`fuzzy=` *number1 number2* `&optional` *fuzz* [*Function*]

This predicate is true if *number1* and *number2* are "roughly equal". The optional argument *fuzz* allows nearly-equal numbers to be considered equal: two numbers *x* and *y* are considered to be equal if the absolute value of their difference is no greater than *fuzz* times the absolute value of the one with the larger absolute value, that is, if $abs(x-y) \le fuzz * max(abs(x), abs(y))$. If no third argument is supplied, then *fuzz* defaults to

```
(max (fuzziness x) (fuzziness y))
```

For example:

`(fuzzy= 2/3 0.6666 0.001)` is true

`fuzziness` *number* [*Function*]

The accuracy of a number, in the absence of any context, is not really a mathematically well-defined concept, because it depends on how the number was calculated and on the accuracy of the givens. Nevertheless the following arbitrary definition of "fuzziness" is offered in its place, for use by `fuzzy=`.

The fuzziness of a rational number is zero. The fuzziness of a floating-point number is $2^{-2f/3}$ where f is the number of bits in the fraction of the floating-point number. The fuzziness of a complex number z is

```
(max (fuzziness (realpart z)) (fuzziness (imagpart z)))
```

14.3. Arithmetic Operations

All of the functions in this section require that their arguments be numbers, and signal an error if given a non-number. They work on all types of numbers, automatically performing any required coercions.

`+ &rest` *numbers* [*Function*]

Returns the sum of the arguments. If there are no arguments, the result is 0, which is an identity for this operation.

Compatibility note: While + is compatible with its use in Lisp Machine LISP, it is incompatible with MACLISP, which uses + for fixnum-only addition.

`-` *number* `&rest` *more-numbers* [*Function*]

The function -, when given one argument, returns the negative of that argument.

The function -, when given more than one argument, subtracts from the first argument all the others, and returns the result.

Compatibility note: While - is compatible with its use in Lisp Machine LISP, it is incompatible with MACLISP, which uses - for fixnum-only subtraction. Also, - differs from `difference` as used in most LISP systems in the case of one argument.

`* &rest` *numbers* [*Function*]

Returns the product of the arguments. If there are no arguments, the result is 1, which is an identity for this operation.

Compatibility note: While * is compatible with its use in Lisp Machine LISP, it is incompatible with MACLISP, which uses * for fixnum-only multiplication.

`/` *number* `&rest` *more-numbers* [*Function*]

The function /, when given more than one argument, divides the first argument by all the others, and returns the result.

With one argument, / reciprocates the argument.

/ will produce a ratio if the mathematical quotient of two integers is not an exact integer.

For example:

```
(/ 12 4) => 3
(/ 13 4) => 13/4
(/ -8) => -1/8
```

To divide one integer by another producing an integer result, use one of the functions `floor`, `ceil`, `trunc`, or `round` (page 128).

If any argument is a floating-point number, then the rules of floating-point contagion apply.

Compatibility note: What / does is totally unlike what the usual // or `quotient` operator does. In most LISP

systems, `quotient` behaves like `/` except when dividing integers, in which case it behaves like `trunc` (page 128) of two arguments; this behavior is mathematically intractable, leading to such anomalies as

```
(quotient 1.0 2.0) => 0.5    but    (quotient 1 2) => 0
```

In practice `quotient` is used only when one is sure that both argument are integers, *or* when one is sure that at least one argument is a floating-point number. `/` is tractable for its purpose, and "works" for *any* numbers. For "integer division", `trunc` (page 128), `floor` (page 128), `ceil` (page 128), and `round` (page 128) are available in COMMON LISP.

`1+` *number* [*Function*]

`1-` *number* [*Function*]

`(1+ x)` is the same as `(+ x 1)`.

`(1- x)` is the same as `(- x 1)`. Note that the short name may be confusing: `(1- x)` does *not* mean $1-x$; rather, it means $x-1$.

Rationale: These are included primarily for compatibility with MACLISP and Lisp Machine LISP. Programmers may wish to avoid the possible confusion in new code.

Implementation note: Compiler writers are very strongly encouraged to ensure that `(1+ x)` and `(+ x 1)` compile into identical code, and similarly for `(1- x)` and `(- x 1)`, to avoid pressure on a LISP programmer to write possibly less clear code for the sake of efficiency. This can easily be done as a source-language transformation.

`incf` *place* [*delta*] [*Macro*]

`decf` *place* [*delta*] [*Macro*]

The number produced by the form *delta* is added to (`incf`) or subtracted from (`decf`) the number in the generalized variable named by *place*, and the sum is stored back into *place* and returned. The form *place* may be any form acceptable as a generalized variable to `setf` (page 50). If *delta* is not supplied, then the number in *place* is changed by 1.

For example:

```
(setq n 0)
(incf n) => 1       and now n => 1
(decf n 3) => -2    and now n => -2
(decf n -5) => 3    and now n => 3
(decf n) => 2       and now n => 2
```

The effect of (`incf` *place delta*) is roughly equivalent to

```
(setf place (+ place delta))
```

except that the latter would evaluate any subforms of *place* twice, while `incf` takes care to evaluate them only once. Moreover, for certain *place* forms `incf` may be significantly more efficient than the `setf` version.

`conjugate` *number* [*Function*]

This returns the complex conjugate of *number*. The conjugate of a non-complex number is itself. For a complex number z,

```
(conjugate z) <=> (complex (realpart z) (- (imagpart z)))
```

`gcd &rest` *rationals* [*Function*]

Returns the greatest common divisor of all the arguments, which must be rationals or complex rationals (complex numbers whose components are rational).

If the arguments are all integers, the result is always a non-negative integer.

If the arguments are all rationals, the result is always a non-negative rational.

If the arguments are all Gaussian integers (complex numbers with integer components), the result is always a first-quadrant Gaussian integer.

In the general case, the result is that complex rational of greatest possible magnitude that is in the first quadrant (including the positive real axis and zero, and excluding the positive imaginary axis) and that when divided into each argument produces a Gaussian integer.

If no arguments are given, `gcd` returns 0, which is an identity for this operation.

??? Query: Is `gcd` of more than two arguments ever really used? If not, is the overhead of the multiple-argument implementation worth the elegance? (Similarly for `lcm`.)

`lcm` *rational* `&rest` *more-rationals* [*Function*]

This returns the least common multiple of its arguments, which must be rationals or complex rationals. For two arguments,

```
(lcm a b) <=> (/ (* a b) (gcd a b))
```

For one argument, `lcm` returns that argument. For three or more arguments,

```
(lcm a b c ... z) <=> (lcm (lcm a b) c ... z)
```

For example:

```
(lcm 14 35) => 70
(lcm 3/4 2/5) => 6
```

14.4. Irrational and Transcendental Functions

`phase` *number* [*Function*]

The phase of a number is the angle part of its polar representation as a complex number. That is,

```
(phase x) <=> (atan (realpart x) (imagpart x))
```

The result is in radians, in the range $(-\pi, \pi]$. The phase of zero is defined to be zero.

`exp` *number* [*Function*]

Returns *e* raised to the power `number`, where *e* is the base of the natural logarithms.

`expt` *base-number power-number* [*Function*]

Returns *base-number* raised to the power *power-number*. If the *base-number* is rational and the *power-number* is an integer, the calculation will be exact and the result will be rational; otherwise a floating-point approximation may result.

Implementation note: If the exponent is an integer a repeated-squaring algorithm may be used, while if the exponent is a floating-point number or complex the result may be calculated as:

```
(exp (* power-number (log base-number)))
```

or in any other reasonable manner.

`log` *number* `&optional` *base* [*Function*]

Returns the logarithm of *number* in the base *base*, which defaults to *e*, the base of the natural logarithms.

For example:

```
(log 8.0 2) => 3.0
(log 0.01 10) => -2.0
```

`abs` *number* [*Function*]

Returns the absolute value of the argument. For a non-complex number,

```
(abs x) <=> (if (minusp x) (- x) x)
```

For a complex number *z*, the absolute value may be computed as

```
(sqrt (+ (expt (realpart z 2)) (expt (imagpart z 2))))
```

For non-complex numbers, `abs` is a rational function, but it may be irrational for complex arguments.

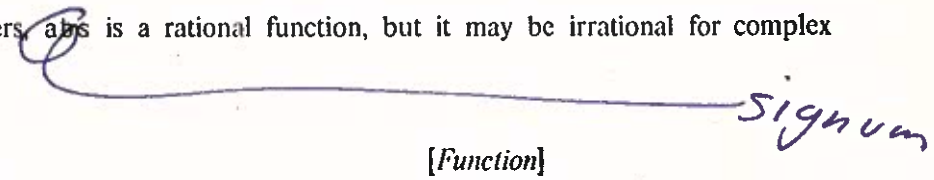
`signum` *number* [*Function*]

By definition,

```
(signum x) <=> (if (zerop x) x (/ x (abs x)))
```

For a rational number, `signum` will return one of `-1`, `0`, or `1` according to whether the number is negative, zero, or positive. For a floating-point number, the result will be a floating-point number of the same format with one of the mentioned three values. For a complex number *z*, (`signum` *z*) is a complex number of the same phase but with unit magnitude.

For non-complex numbers, `abs` is a rational function, but it may be irrational for complex arguments.



`sqrt` *number* [*Function*]

Returns the principal square root of *number*.

`isqrt` *integer* [*Function*]

Integer square-root: the argument must be a non-negative integer, and the result is the greatest integer less than or equal to the exact positive square root of the argument.

`sin` *radians* [*Function*]
`cos` *radians* [*Function*]
`tan` *radians* [*Function*]

`sin` returns the sine of the argument, `cos` the cosine, and `tan` the tangent. The argument is in radians. The argument may be complex.

`cis` *radians* [*Function*]

This computes $e^{i*radians}$. The name "`cis`" means "cos + i sin", because $e^{i\theta} = \cos\theta + i\sin\theta$. The argument is in radians, and may be any non-complex number. The result is a complex number whose real part is the cosine of the argument, and whose imaginary part is the sine. Put another way, the result is a complex number whose phase is the argument and whose magnitude is unity.

Implementation note: Often it is cheaper to calculate the sine and cosine of a single angle together than to perform two disjoint calculations.

`asin` *number* [*Function*]
`acos` *number* [*Function*]

`asin` returns the arcsine of the argument, and `cos` the arccosine. The result is in radians. The argument may be complex.

`atan` *y* `&optional` *x* [*Function*]

An arctangent is calculated and the result is returned in radians.

With two arguments y and x, neither argument may be complex. The result is the arctangent of the quantity y/x. The signs of y and x are used to derive quadrant information; moreover, x may be zero provided y is not zero. The value of `atan` is always between $-\pi$ (exclusive) and π (inclusive). The following table details various special cases.

Condition		Cartesian locus	Range of result
$y = 0$	$x > 0$	Positive x-axis	0
$y > 0$	$x > 0$	Quadrant I	$0 < \text{result} < \pi/2$
$y > 0$	$x = 0$	Positive y-axis	$\pi/2$
$y > 0$	$x < 0$	Quadrant II	$\pi/2 < \text{result} < \pi$
$y = 0$	$x < 0$	Negative x-axis	π
$y < 0$	$x < 0$	Quadrant III	$-\pi < \text{result} < -\pi/2$
$y < 0$	$x = 0$	Negative y-axis	$-\pi/2$
$y < 0$	$x > 0$	Quadrant IV	$-\pi/2 < \text{result} < 0$
$y = 0$	$x = 0$	Origin	error

Actually, the < signs in the above table ought to be ≤ signs, because of rounding effects; if y is greater than zero but nevertheless very small, then the floating-point approximation to $\pi/2$ might be a more accurate result than any other floating-point number. (For that matter, when y = 0 the

exact value $\pi/2$ cannot be produced anyway, but instead only an approximation.)

With only one argument y, the argument may be complex. The result is the arctangent of y. For non-complex arguments the result lies between $-\pi/2$ and $\pi/2$ (both exclusive).

Compatibility note: MACLISP has a function called `atan` which range from 0 to 2π. Every other language in the world (ANSI FORTRAN, IBM PL/I, InterLISP) has an arctangent function with range $-\pi$ to π. Lisp Machine LISP provides two functions, `atan` (compatible with MACLISP) and *atan2* (compatible with everyone else).

COMMON LISP makes `atan` the standard one with range $-\pi$ to π. Observe that this makes the one-argument and two-argument versions of `atan` compatible in the sense that the branch cuts do not fall in different places, which is probably why most languages use this definition. (An aside: the INTERLISP one-argument function `arctan` has a range from 0 to π, while every other language in the world provides the range $-\pi/2$ to $\pi/2$! Nevertheless, since INTERLISP uses the standard two-argument version, its branch cuts are inconsistent anyway.)

`pi` [*Variable*]

This global variable has as its value the best possible approximation to π in the largest floating-point format provided by the implementation.

For example:

```
(defun sind (x)                    ;The argument is in degrees.
  (sin (* x (/ pi 180))))
```

An approximation to π in some other precision can be obtained by writing `(float pi x)`, where x is a floating-point number of the desired precision; see `float` (page 126).

`sinh` *number* [*Function*]
`cosh` *number* [*Function*]
`tanh` *number* [*Function*]
`asinh` *number* [*Function*]
`acosh` *number* [*Function*]
`atanh` *number* [*Function*]

These functions compute the hyperbolic sine, cosine, tangent, arcsine, arccosine, and arctangent functions, which are mathematically defined as follows:

Hyperbolic sine	$(e^x - e^{-x})/2$
Hyperbolic cosine	$(e^x + e^{-x})/2$.
Hyperbolic tangent	$(e^x - e^{-x})/(e^x + e^{-x})$
Hyperbolic arcsine ??? # # #	
Hyperbolic arccosine	
Hyperbolic arctangent	

Implementation note: These formulae are mathematically correct, assuming completely accurate computation. They may be terrible methods for floating-point computation! Implementors should consult a good text on numerical analysis.

14.5. Type Conversions and Component Extractions on Numbers

While most arithmetic functions will operate on any kind of number, coercing types if necessary, the following functions are provided to allow specific conversions of data types to be forced, when desired.

`float` *number* `&optional` *other* [*Function*]

Converts any non-complex number to a floating-point number. With no second argument, then if a given format of floating-point number is sufficiently precise to represent the result, then the result may be of that format or of any larger format, depending on the implementation; but if no fixed format is sufficiently precise, then the format of greatest precision provided by the implementation is used.

If the argument *other* is provided, then it must be a floating-point number, and *number* is converted to the same format as *other*.

`rational` *number* [*Function*]

`rationalize` *number* `&optional` *tolerance* [*Function*]

Each of these functions converts any non-complex number to be a rational number. If the argument is already rational, that argument is returned. The two functions differ in their treatment of floating-point numbers.

`rational` assumes that the floating-point number is completely accurate, and returns a rational number mathematically equal to the precise value of the floating-point number. This is (probably) much faster than `rationalize`.

`rationalize` assumes that the floating-point number is accurate only to the precision of the floating-point representation, and may return any rational number for which the floating-point number is the best available approximation; in doing this it attempts to keep both numerator and denominator small. It is always the case that

```
(eql (float (rationalize x) x) x)
```

That is, rationalizing a floating-point number and then converting it back to a floating-point number of the same format produces the original number.

The optional argument *tolerance* may be used to alter the assumption concerning precision. If *tolerance* is a positive integer, then *number* is assumed to be accurate to only that many bits. If it is a negative integer, then *number* is assumed to be accurate only to within that many bits of the low end of the fraction. If it is a positive floating-point number, then it is a relative tolerance; *number* is assumed to be precise only to an amount equal to *number* times *tolerance*.

??? Query: (1) Should *tolerance* be applied even if the argument is not a floating-point number? For example, `(rationalize 113/355 0.01)` might produce `22/7`.

(2) Should the third argument to `fuzzy=` be like the second argument to `rationalize`? Then perhaps we could make the claim that

```
(fuzzy= (float (rationalize x tol) x) x tol)
```

for all `x` and `tol`.

`numerator` *rational* [*Function*]
`denominator` *rational* [*Function*]

These functions take a rational number (an integer or ratio) and return as an integer the numerator or denominator of the canonical reduced form of the rational. The numerator of an integer is that integer, and the denominator of an integer is 1. Note that

```
(gcd (numerator x) (denominator x)) => 1
```

rational *x*.

For example:

```
(numerator (/ 8 -6)) => -4
(denominator (/ 8 -6)) => 3
```

There is no `fix` function in COMMON LISP, because there are several interesting ways to convert non-integral values to integers. These are provided by the functions below, which perform not only type-conversion but also some non-trivial calculations.

`floor` *number* `&optional` *divisor* [*Function*]
`ceil` *number* `&optional` *divisor* [*Function*]
`trunc` *number* `&optional` *divisor* [*Function*]
`round` *number* `&optional` *divisor* [*Function*]

In the simple, one-argument case, each of these functions converts its argument *number* (which may not be complex) to be an integer. If the argument is already an integer, it is returned directly. If the argument is a ratio or floating-point number, the functions use different algorithms for the conversion.

`floor` converts its argument by truncating towards negative infinity; that is, the result is the largest integer which is not larger than the argument.

`ceil` converts its argument by truncating towards positive infinity; that is, the result is the smallest integer which is not smaller than the argument.

`trunc` converts its argument by truncating towards zero; that is, the result is the integer of the same sign as the argument and which has the greatest integral magnitude not greater than that of the argument.

`round` converts its argument by rounding to the nearest integer; if *number* is exactly halfway between two integers (that is, of the form *integer*+0.5) then it is rounded to the one which is even (divisible by two).

Here is a table showing what the four functions produce when given various arguments.

Argument	floor	ceiling	trunc	round
2.6	2	3	2	3
2.5	2	3	2	2
2.4	2	3	2	2
0.7	0	1	0	1
0.3	0	1	0	0
-0.3	-1	0	0	0
-0.7	-1	0	0	-1
-2.4	-3	-2	-2	-2
-2.5	-3	-2	-2	-2
-2.6	-3	-2	-2	-3

If a second argument *divisor* is supplied, then the result is the appropriate type of rounding or truncation applied to the result of dividing the *number* by the *divisor*. For example, `(floor 5 2) = (floor (/ 5 2))`, but is potentially more efficient. The *divisor* may be any non-complex number. The one-argument case is exactly like the two-argument case where the second argument is 1.

Each of the functions actually returns *two* values; the second result is the remainder, and may be obtained using `multiple-value-let` (page MULTIPLE-VALUE-LET-FUN) and related constructs. If any of these functions is given two arguments x and y and produces results q and r, then $q*y+r=x$. The remainder r is an integer if both arguments are integers, is rational if both arguments are rational, and is floating-point if either argument is floating-point. (In the one-argument case the remainder is a number of the same type as the argument.) The first result is always an integer.

Compatibility note: The names of the functions `floor`, `ceil`, `trunc`, and `round` are more accurate than names like `fix` which have heretofore been used in various LISP systems. The names used here are compatible with standard mathematical terminology (and with PL/I, as it happens). In FORTRAN `ifix` means `trunc`. ALGOL 68 provides `round`, and uses `entier` to mean `floor`. In MACLISP, `fix` and `ifix` both mean `floor` (one is generic, the other flonum-in/fixnum-out). In INTERLISP, `fix` means `trunc`. In Lisp Machine LISP, `fix` means `floor` and `fixr` means `round`. STANDARD LISP provides a `fix` function, but does not accurately specify what it does exactly. The existing usage of the name `fix` is so confused that it seems best to avoid it altogether.

The names and definitions given here have recently been adopted by Lisp Machine LISP, and MACLISP and NIL seem likely to follow suit.

`mod` *number* `&optional` *divisor tolerance* [*Function*]
`remainder` *number* `&optional` *divisor tolerance* [*Function*]

If the optional argument *tolerance* is omitted, `mod` performs the operation `floor` (page 160) on its arguments, and returns the *second* result of `floor` as its only result. Similarly, `remainder` performs the operation `trunc` (page 160) on its arguments, and returns the *second* result of `trunc` as its only result.

`mod` and `remainder` are therefore the usual modulus and remainder functions when applied to two integer arguments. In general, however, the arguments may be integers or floating-point numbers.

With one argument, these functions perform the "mod 1" or "fractional part" operation, differing in the direction of rounding: the result of `mod` of one argument is always non-negative, while the

result of `remainder` of one argument always has the same sign as the argument.

```
(mod 13 4) => 1                    (remainder 13 4) => 1
(mod -13 4) => 3                   (remainder -13 4) => -1
(mod 13 -4) => -3                  (remainder 13 -4) => 1
(mod -13 -4) => -1                 (remainder -13 -4) => -1
(mod 13.4) => 0.4                  (remainder 13.4) => 0.4
(mod -13.4) => 0.6                 (remainder -13.4) => -0.4
```

If the optional argument *tolerance* is given, then it is handled in the following manner. Like the optional argument *tolerance* to `rationalize`, it may be a positive or negative integer or a positive floating-point number. For expository purposes define `(delta` *x*`)`, for a floating-point number *x*, to be one-half the value of the smallest floating-point number *y* of the same format as *x* such that

```
(> (+ y (float 1 x)) x)
```

Then define the function `compute-tolerance` as follows:

```
(defun compute-tolerance (x tol)
  (cond ((floatp tol) tol)
        ((minusp tol) (* (delta x) (expt 2 (- tol))))
        (t (expt 2 (- tol)))))
```

Now when `mod` or `remainder` performs its computation, it is as if it called `floor` or `trunc` and returned the second result. Let the *first* result from `floor` or `trunc` be called *q*; this will be an integer. If `mod` or `remainder` is given the optional argument *tolerance*, it will signal an error, rather than delivering a result, if *number* is a floating-point number and

```
(> (* q (delta number)) (compute-tolerance number tolerance))
```

The interpretation is that *tolerance* is a measure of the accuracy required of the computed remainder. If the quotient *q* is very large, then the original *number* must have been so large relative to the *divisor* that the remainder cannot be very accurate.

`ffloor` *number* `&optional` *divisor* [*Function*]
`fceil` *number* `&optional` *divisor* [*Function*]
`ftrunc` *number* `&optional` *divisor* [*Function*]
`fround` *number* `&optional` *divisor* [*Function*]

These functions are just like `floor`, `ceil`, `trunc`, and `round`, except that the result (the first result of two) is always a floating-point number rather than an integer. It is roughly as if `ffloor` gave its arguments to `floor`, and then applied `float` to the first result before passing them both back. In practice, however, `ffloor` may be implemented much more efficiently. Similar remarks apply to the other three functions. If the first argument is a floating-point number, and the second agrument is not a floating-point number of shorter format, then the first result will be a floating-point number of the same type as the first argument.

For example:

```
(ffloor -4.7) => -5.0 and 0.3
(ffloor 3.5d0) => 3.0d0 and 0.5d0
```

`complex` *realpart* `&optional` *imagpart* [*Function*]

The arguments must be non-complex numbers; a complex number is returned that has *realpart* as its real part and *imagpart* as its imaginary part. If *imagpart* is not specified then `(* realpart 0)` is used (this has the effect that the two parts are both rational or both floating-point numbers of the same format).

`realpart` *number* [*Function*]

`imagpart` *number* [*Function*]

These return the real and imaginary parts of a complex number. If *number* is a non-complex number, then `realpart` returns its argument *number* and `imagpart` returns `(* number 0)` (this has the effect that the imaginary part of a rational is 0 and that of a floating-point number is a floating-point zero of the same format).

??? Query: What would be the pros and cons of *requiring* the two parts of a complex number to be either both rational or both floating-point numbers of the same format?

14.6. Logical Operations on Numbers

The logical operations in this section treat integers as if they were represented in two's-complement notation.

Implementation note: Internally, of course, an implementation of COMMON LISP may or may not use a two's-complement representation. All that is necessary is that the logical operations perform calculations so as to give this appearance to the user.

The logical operations provide a convenient way to represent an infinite vector of bits. Let such a conceptual vector be indexed by the non-negative integers. Then bit j is assigned a "weight" 2^j. Assume that only a finite number of bits are ones, or that only a finite number of bits are zeros. A vector with only a finite number of one-bits is represented as the sum of the weights of the one-bits, a positive integer. A vector with only a finite number of zero-bits is represented as `-1` minus the sum of the weights of the zero-bits, a negative integer.

This method of using integers to represent bit vectors can in turn be used to represent sets. Suppose that some (possibly countably infinite) universe of discourse for sets is mapped into the non-negative integers. Then a set can be represented as a bit vector; an element is in the set if the bit whose index corresponds to that element is a one-bit. In this way all finite sets can be represented (by positive integers), as well as all sets whose complements are finite (by negative integers). The functions `logior`, `logand`, and `logxor` defined below then compute the union, intersection, and symmetric difference operations on sets represented in this way.

`logior &rest` *integers* [*Function*]

Returns the bit-wise logical *inclusive or* of its arguments. If no argument is given, then the result is zero, which is an identity for this operation.

`logxor &rest` *integers* [*Function*]

Returns the bit-wise logical *exclusive or* of its arguments. If no argument is given, then the result is zero, which is an identity for this operation.

`logand &rest` *integers* [*Function*]

Returns the bit-wise logical *and* of its arguments. If no argument is given, then the result is `-1`, which is an identity for this operation.

`logeqv &rest` *integers* [*Function*]

Returns the bit-wise logical *equivalence* (also known as *exclusive nor*) of its arguments. If no argument is given, then the result is `-1`, which is an identity for this operation.

`lognand` *integer1 integer2* [*Function*]
`lognor` *integer1 integer2* [*Function*]
`logandc1` *integer1 integer2* [*Function*]
`logandc2` *integer1 integer2* [*Function*]
`logorc1` *integer1 integer2* [*Function*]
`logorc2` *integer1 integer2* [*Function*]

These are the other six non-trivial bit-wise logical operations on two arguments. Because they are not commutative or associative, they take exactly two arguments rather than any non-negative number of arguments.

```
(lognand n1 n2) <=> (lognot (logand n1 n2))
 (lognor n1 n2) <=> (lognot (logor n1 n2))
(logandc1 n1 n2) <=> (logand (lognot n1) n2)
(logandc2 n1 n2) <=> (logand n1 (lognot n2))
 (logorc1 n1 n2) <=> (logor (lognot n1) n2)
 (logorc2 n1 n2) <=> (logor n1 (lognot n2))
```

The ten bit-wise logical operations on two integers are summarized in this table:

Argument 1	0	0	1	1	
Argument 2	0	1	0	1	*Operation name*
`logand`	0	0	0	1	and
`logior`	0	1	1	1	inclusive or
`logxor`	0	1	1	0	exclusive or
`logeqv`	1	0	0	1	equivalence (exclusive nor)
`lognand`	1	1	1	0	not-and
`lognor`	1	0	0	0	not-or
`logandc1`	0	1	0	0	and complement of arg1 with arg2
`logandc2`	0	0	1	0	and arg1 with complement of arg2
`logorc1`	1	1	0	1	or complement of arg1 with arg2
`logorc2`	1	0	1	1	or arg1 with complement of arg2

`boole` *op integer1 integer2* [*Function*]

`boole-clr` [*Variable*]

`boole-set` [*Variable*]

`boole-1` [*Variable*]

`boole-2` [*Variable*]

`boole-c1` [*Variable*]

`boole-c2` [*Variable*]

`boole-and` [*Variable*]

`boole-ior` [*Variable*]

`boole-xor` [*Variable*]

`boole-eqv` [*Variable*]

`boole-nand` [*Variable*]

`boole-nor` [*Variable*]

`boole-andc1` [*Variable*]

`boole-andc2` [*Variable*]

`boole-orc1` [*Variable*]

`boole-orc2` [*Variable*]

The function `boole` takes an operation *op* and two integers, and returns an integer produced by performing the logical operation specified by *op* on the two integers. The precise values of the sixteen variables are implementation-dependent, but they are suitable for use as the first argument to `boole`:

	integer1	0	0	1	1	
	integer2	0	1	0	1	*Operation performed*
`boole-clr`		0	0	0	0	always 0
`boole-set`		1	1	1	1	always 1
`boole-1`		0	0	1	1	integer1
`boole-2`		0	1	0	1	integer2
`boole-c1`		1	1	0	0	complement of integer1
`boole-c2`		1	0	1	0	complement of integer2
`boole-and`		0	0	0	1	and
`boole-ior`		0	1	1	1	inclusive or
`boole-xor`		0	1	1	0	exclusive or
`boole-eqv`		1	0	0	1	equivalence (exclusive nor)
`boole-nand`		1	1	1	0	not-and
`boole-nor`		1	0	0	0	not-or
`boole-andc1`		0	1	0	0	and complement of integer1 wi
`boole-andc2`		0	0	1	0	and integer1 with complement
`boole-orc1`		1	1	0	1	or complement of integer1 wit
`boole-orc2`		1	0	1	1	or integer1 with complement o

`boole` can therefore compute all sixteen logical functions on two arguments. In general,

```
(boole boole-and x y) <=> (logand x y)
```

and the latter is more perspicuous. However, `boole` is useful when it is necessary to parameterize a procedure so that it can use one of several logical operations.

`lognot` *integer* [*Function*]

Returns the bit-wise logical *not* of its argument. Every bit of the result is the complement of the corresponding bit in the argument.

```
(logbitp j (lognot x)) <=> (not (logbitp j x))
```

`logtest` *integer1 integer2* [*Function*]

`logtest` is a predicate which is true if any of the bits designated by the 1's in *integer1* are 1's in *integer2*.

```
(logtest x y) <=> (not (zerop (logand x y)))
```

`logbitp` *index integer* [*Function*]

logbitp is true if the bit in *integer* whose index is *index* (that is, its weight is 2^{index}) is a one-bit; otherwise it is false.

For example:

```
(logbitp 2 6) is true
(logbitp 0 6) is false
(logbitp k n) <=> (ldb-test (byte 1 k) n)
```

`ash` *integer count* [*Function*]

Shifts *integer* arithmetically left by *count* bit positions if *count* is positive, or right *-count* bit positions if *count* is negative. The sign of the result is always the same as the sign of *integer*.

Arithmetically, this operation performs the computation *floor*(*integer**2^{count}).

Logically, this moves all of the bits in *integer* to the left, adding zero-bits at the bottom, or moves them to the right, discarding bits. (In this context the question of what gets shifted in on the left is irrelevant; integers, viewed as strings of bits, are "half-infinite", that is, conceptually extend infinitely far to the left.)

For example:

```
(logbitp j (ash n k))
   <=> (and (>= j k) (logbitp (- j k) n))
```

`logcount` *integer* [*Function*]

The number of bits in *integer* is determined and returned. If *integer* is positive, then 1 bits in its binary representation are counted. If *integer* is negative, then the 0 bits in its two's-complement binary representation are counted. The result is always a non-negative integer.

For example:

```
(logcount 13) => 3          ; Binary representation is ...0001101
(logcount -13) => 2         ; Binary representation is ...1110011
(logcount 30) => 4          ; Binary representation is ...0011110
(logcount -30) => 4         ; Binary representation is ...1100010
```

As a rule,

```
(logcount x) <=> (logcount (- (+ x 1)))
```

`haulong` *integer* [*Function*]

This returns the number of significant bits in the absolute value of *integer*. The precise computation performed is *ceiling*(log2(*abs*(*integer*)+1)).

For example:

```
(haulong 0) => 0
(haulong 3) => 2
(haulong 4) => 3
(haulong -7) => 3
```

`haipart` *integer count* [*Function*]

Returns the high *count* bits of the binary representation of the absolute value of *integer*, or the low *-count* bits if *count* is negative. A possible definition of `haipart`:

```
(defun haipart (integer count)
    (let ((x (abs integer)))
         (if (minusp count)
             (ldb (byte (- count) 0) x)
             (ldb (byte count (max (- (haulong x) n) 0))
                  x))))
```

14.7. Byte Manipulation Functions

Several functions are provided for dealing with an arbitrary-width field of contiguous bits appearing anywhere in an integer. Such a contiguous set of bits is called a *byte*. Here the term *byte* does not imply some fixed number of bits (such as eight), but a field of arbitrary and user-specifiable width.

The byte-manipulation functions use objects called *byte specifiers* to designate a specific byte position within an integer. The representation of a byte specifier is implementation-dependent; it is sufficient to know that the function *byte* will construct one, and that the byte-manipulation functions will accept them. The function *byte* accepts two integers representing the *position* and *size* of the byte, and returns a byte specifier. Such a specifier designates a byte whose width is *size*, and whose right-hand bit has weight $2^{position}$, in the terminology of integers used as logical bit vectors.

`byte` *size position* [*Function*]

byte takes two integers representing the size and position of a byte, and returns a byte specifier suitable for use as an argument to byte-manipulation functions.

`byte-size` *bytespec* [*Function*]

`byte-position` *bytespec* [*Function*]

Given a byte specifier, `byte-size` returns the size specified as an integer; `byte-position` similarly returns the position.

For example:

```
(byte-size (byte j k)) <=> k
(byte-position (byte j k)) <=> j
```

`ldb` *bytespec integer* [*Function*]

bytespec specifies a byte of *integer* to be extracted. The result is returned as a positive integer.

For example:

```
(logbitp j (ldb (byte s p) n)
   <=> (and (< j s) (logbitp (+ j p) n))
```

The name of the function "`ldb`" means "load byte".

`ldb-test` *bytespec integer* [*Function*]

`ldb-test` is a predicate which is true if any of the bits designated by the byte specifier *bytespec* are 1's in *integer*; that is, it is true if the designated field is non-zero.

```
(ldb-test bytespec n) <=> (not (zerop (ldb bytespec n)))
```

`mask-field` *bytespec integer* [*Function*]

This is similar to `ldb`; however, the result contains the specified byte of *integer* in the position specified by *bytespec*, rather than in position 0 as with `ldb`. The result therefore agrees with *integer* in the byte specified, but has zero bits everywhere else.

For example:

```
(ldb bs (mask-field bs n)) <=> (ldb bs n)
(logbitp j (mask-field (byte s p) n))
   <=> (and (>= j p) (< j s) (logbitp j n))
(mask-field bs n) <=> (logand n (ldb bs -1))
```

`dpb` *newbyte bytespec integer* [*Function*]

Returns a number which is the same as *integer* except in the bits specified by *bytespec*. Let *s* be the size specified by *bytespec*; then the low *s* bits of *newbyte* appear in the result in the byte specified by *bytespec*. The integer *newbyte* is therefore interpreted as being right-justified, as if it were the result of `ldb`.

For example:

```
(logbitp j (dpb m (byte s p) n))
   <=> (if (and (>= j p) (< j (+ p s)))
           (logbitp (- j p) m)
           (logbitp j n))
```

The name of the function "`dpb`" means "deposit byte".

`deposit-field` *newbyte bytespec integer* [*Function*]

This function is to `mask-field` as `dpb` is to `ldb`. The result is an integer which contains the bits of *newbyte* within the byte specified by *bytespec*, and elsewhere contains the bits of *integer*.

For example:

```
(logbitp j (dpb m (byte s p) n))
   <=> (if (and (>= j p) (< j (+ p s)))
           (logbitp j m)
           (logbitp j n))
```

14.8. Random Numbers

`random` `&optional` *number1 number2* [*Function*]

`(random)` returns a random integer, which may be positive or negative. The range of the result is implementation-dependent but reasonably large.

Implementation note: In practice the result should range over all the fixnums.

??? Query: Suggest that zero-argument `random` should be flushed as being too implementation-dependent? Yes!

`(random n)` accepts a positive number *n* and returns a number of the same kind between zero (inclusive) and *n* (exclusive). The number *n* may be an integer or a floating-point number. An approximately uniform choice distribution is used; If *n* is an integer, each of the possible results

occurs with (approximate) probability $1/n$.

`(random low high)` is equivalent to `(+ low (random (- high low)))`; it provides a choice from the range *low* (inclusive) to *high* (exclusive).

Compatibility note: In INTERLISP, the range limits are both inclusive. Would this be more intuitive? It is easy to implement for integers, but much harder for floating-point numbers.

Implementation note: In general, it is not adequate to define `(random n)` for integral n to be `(mod (random) n)`; this fails to be uniformly distributed if n is larger than the largest number produced by `random`, or even if n merely approaches this number. Assuming that the underlying mechanism produces "random bits" (possibly in chunks such as fixnums), the best approach is to produce enough random bits to construct an integer k some number d of bits larger than `(haulong n)` (see `haulong` (page 167)), and then compute `(mod k n)`. The quantity d should be at least 7, and preferably 10 or more.

To produce random floating-point numbers in the range $[A, B)$, accepted practice (as determined by a quick look through the *Collected Algorithms from the ACM*, particularly algorithms 133, 266, 294, and 370) is to compute $X*(B-A)+A$, where X is a floating-point number uniformly distributed over [0.0, 1.0) and computed by calculating a random integer N in the range $[0, M)$ (typically by a multiplicative-congruential or linear-congruential method mod M) and then setting $X=N/M$. If one takes $M = 2^f$, where f is the length of the fraction of a floating-point number (and it is in fact common to choose M to be a power of two), then this method is equivalent to the following assembly-language-level procedure. Assume the representation has no hidden bit. Take a floating-point 0.5, and clobber its entire fraction with random bits. Normalize the result if necessary.

For example, on the PDP-10, assume that accumulator T is completely random (all 36 bits are random). Then the code sequence

```
LSH T,-9          ;Clear high 9 bits; low 27 are random.
FSC T,128.        ;Install exponent and normalize.
```

will produce in T a random floating-point number uniformly distributed over [0.0, 1.0). (Instead of the LSH, one could do "TLO T,777000; but if the 36 random bits came from a congruential random-number generator, the high-order bits tend to be "more random" than the low-order ones, and so the LSH would be a bit better for uniform distribution. Ideally all the bits would be the result of high-quality randomness.)

With a hidden-bit representation, normalization is not a problem, but dealing with the hidden bit is. The method can be adapted as follows. Take a floating-point 1.0 and clobber the explicit fraction bits with random bits; this produces a random floating-point number in the range [1.0, 2.0). Then simply subtract 1.0. In effect, we let the hidden bit creep in and then subtract it away again.

For example, on the VAX, assume that register T is completely random (but a little less random than on the PDP-10, as it has only 32 random bits). Then the code sequence

```
INSV #^X81,#7,#9,T      ;Install correct sign bit and exponent.
SUBF #^F1.0,T           ;Subtract 1.0.
```

will produce in T a random floating-point number uniformly distributed over [0.0, 1.0). Again, if the low-order bits are not random enough, then "ROTL #7,T" should be performed first.

`random-state` [*Variable*]

This variable holds a data structure which encodes the internal state of the random-number generator used by `random`. The nature of this data structure is implementation-dependent. It may be printed out and successfully read back in, but may or may not function correctly as a random-number state object in another implementation. A call to `random` will perform a side effect on this data structure. Lambda-binding this variable to a different random-number state object will correctly save and restore the old state object, of course.

`random-state &optional` *state* [*Function*]

This function returns a new random-number state object, suitable for use as the value of the variable `random-state`. If *state* is ( ) or omitted, `random-state` returns a *copy* of the current random-number state object (the value of the variable `random-state`). If *state* is a state object, a copy of that state object is returned. If *state* is `t`, then a new state object is returned which has been "randomly" initialized by some means (such as by a time-of-day clock).

Chapter 15

Characters

COMMON LISP provides a character data type; objects of this type represent printed symbols such as letters.

Every character has three attributes: code, bits, and font. The code attribute is intended to distinguish among the printed glyphs and formatting functions for characters. The bits attribute allows extra flags to be associated with a character. The font attribute permits a specification of the style of the glyphs (such as italics).

`char-code-limit` [*Variable*]

The initial global value of `char-code-limit` is a non-negative integer which is the upper exclusive bound on values produced by the function `char-code` (page 143), which returns the *code* component of a given character; that is, the values returned by `char-code` are non-negative and strictly less than the value of `char-code-limit`.

Implementation note: For the PERQ, the value will be 256; for the S-1, 512.

`char-font-limit` [*Variable*]

The initial global value of `char-font-limit` is a non-negative integer which is the upper exclusive bound on values produced by the function `char-font` (page 143), which returns the *font* component of a given character; that is, the values returned by `char-font` are non-negative and strictly less than the value of `char-font-limit`.

Implementation note: No COMMON LISP implementation is required to support non-zero font attributes; if it does not, then `char-font-limit` should be 1. For the PERQ, the value will be 256; for the S-1, 512.

`char-bits-limit` [*Variable*]

The initial global value of `char-bits-limit` is a non-negative integer which is the upper exclusive bound on values produced by the function `char-bits` (page 143), which returns the *bits* component of a given character; that is, the values returned by `char-bits` are non-negative and strictly less than the value of `char-bits-limit`. Note that the value of `char-bits-limit` will be a power of two.

Implementation note: No COMMON LISP implementation is required to support non-zero bits attributes; if it does not, then `char-bits-limit` should be 1. For the PERQ, the value will be 256; for the S-1, 512.

15.1. Predicates on Characters

The predicate `characterp` (page 38) may be used to determine whether any LISP object is a character object.

`standard-charp` *char* [*Function*]

The argument *char* must be a character object. `standard-charp` is true if the argument is a "standard character", that is, one of the ninety-five ASCII printing characters or <return>. If the argument is a non-standard character, then `standard-charp` is false.

Note in particular that any character with a non-zero *bits* or *font* attribute is non-standard.

`graphicp` *char* [*Function*]

The argument *char* must be a character object. `graphicp` is true if the argument is a "graphic" (printing) character, and false if it is a "non-graphic" (formatting or control) character. Graphic characters have a standard textual representation as a single glyph, such as "`A`" or "`*`" or "`=`". By convention, the space character is considered to be graphic. Of the standard characters (as defined by `standard-charp`), all but <return> are graphic. If an implementation provides any of <backspace>, <tab>, <rubout>, <linefeed>, and <form>, they are not graphic.

Graphic characters of font 0 may be assumed all to be of the same width when printed; programs may depend on this for purposes of columnar formatting. Non-graphic characters and characters of other fonts may be of varying widths.

Any character with a non-zero bits attribute is non-graphic.

`string-charp` *char* [*Function*]

The argument *char* must be a character object. `string-charp` is true if *char* can be stored into a string (see the functions `char` (page 149) and `rplachar` (page 150)), and otherwise is false. Any character which satisfies `standard-charp` and `graphicp` also satisfies `string-charp`; others may also.

`alphap` *char* [*Function*]

The argument *char* must be a character object. `alphap` is true if the argument is an alphabetic character, and otherwise is false.

Of the standard characters (as defined by `standard-charp`), the letters "A" through "Z" and "a" through "z" are alphabetic.

`uppercasep` *char* [*Function*]
`lowercasep` *char* [*Function*]
`bothcasep` *char* [*Function*]

The argument *char* must be a character object. `uppercasep` is true if the argument is an upper-

case (majuscule) character, and otherwise is false. `lowercasep` is true if the argument is an lower-case (minuscule) character, and otherwise is false.

`bothcasep` is true if the argument is upper-case *and* there is a corresponding lower-case character (which can be obtained using `char-downcase` (page 144)), or if the argument is lower-case and there is a corresponding upper-case character (which can be obtained using `char-upcase` (page 144)).

If a character is either upper-case or lower-case, it is necessarily alphabetic. However, it is permissible in theory for an alphabetic character to be neither uppercase nor lowercase.

Of the standard characters (as defined by `standard-charp`), the letters "A" through "Z" are upper-case and "a" through "z" are lower-case.

`digitp` *char* `&optional` (*radix* `10.`) [*Function*]

The argument *char* must be a character object, and *radix* must be a non-negative integer. `digitp` is a pseudo-predicate: if *char* is not a digit of the radix specified by *radix*, then it is false; otherwise it returns a non-negative integer which is the "weight" of *char* in that radix.

Digits are necessarily graphic characters.

Of the standard characters (as defined by `standard-charp`), the characters "0" through "9", "A" through "Z", and "a" through "z" are digits. The weights of "0" through "9" are the integers 0 through 9, and of "A" through "Z" (and also "a" through "z") are 10 through 35. `digitp` returns the weight for one of these digits if and only if its weight is strictly less than *radix*. Thus, for example, the digits for radix 16 are "0123456789ABCDEF".

```
(defun convert-string-to-integer (str &optional (radix 10))
  "Given a digit string and optional radix, return an integer."
  (do ((j 0 (+ j 1))
       (n 0 (+ (* n radix)
               (or (digitp (char str j) radix)
                   (ferror "Bad radix-~D digit: ~C"
                           radix
                           (char str i))))))
      ((= j (string-length str)) n)))
```

`alphanumericp` *char* [*Function*]

The argument *char* must be a character object. `alphanumericp` is true if *char* is either alphabetic or numeric. By definition,

```
(alphanumericp x) <=> (or (alphap x) (digitp x))
```

Alphanumeric characters are therefore are necessarily graphic (as defined by `graphicp` (page 174)).

Of the standard characters (as defined by `standard-charp`), the characters "0" through "9", "A" through "Z", and "a" through "z" are alphanumeric.

`char=` *char1 char2* [*Function*]

The arguments *char1* and *char2* must be character objects. `char=` is true if *char1* and *char2* are equivalent character objects, having equivalent attributes, and otherwise is false.

The function `CHAR=` is the finest discriminator of characters available to the programmer. If `(char= c1 c2)` is true, then any function professing to operate on a character must behave the same whether given `c1` or `c2`.

For non-"funny" characters (those not satisfying `funny-charp` (page FUNNY-CHARP-FUN)),

```
(CHAR= C1 C2) <=>
      (AND (= (CHAR-CODE C1) (CHAR-CODE C2))
           (= (CHAR-BITS C1) (CHAR-BITS C2))
           (= (CHAR-FONT C1) (CHAR-FONT C2)))
```

There is no requirement that `(eq c1 c2)` be true merely because `(char= c1 c2)` is true. While `eq` may distinguish two character objects that `char=` does not, it is distinguishing them not as *characters*, but in some sense on the basis of a lower-level implementation characteristic. (Of course, if `(eq c1 c2)` is true then one may expect `(char= c1 c2)` to be true.) However, `eql` (page 39) and `equal` (page 40) compare character objects in the same way that `char=` does.

`char-equal` *char1 char2* [*Function*]

The arguments *char1* and *char2* must be character objects.

The predicate `char-equal` is like `char=`, except that it ignores differences of font and bits attributes and case. By definition,

```
(char-equal c1 c2) <=>
      (char= (char-upcase (character c1))
             (char-upcase (character c2)))
```

For example:

`(char-equal #\A #\a)` is true
`(char= #\A #\a)` is false
`(char-equal #\A (control #\A))` is true

`char<` *char1 char2* [*Function*]
`char>` *char1 char2* [*Function*]

The arguments *char1* abd *char2* must be character objects. The predicate `char<` is true if *char1* precedes *char2* in the (implementation-dependent) total ordering on characters. The predicate `char>` is true if *char1* follows *char2* in the (implementation-dependent) total ordering on characters. Neither is true if the arguments satisfy `char=` (page 142).

The total ordering on characters is guaranteed to have the following properties:

- The alphanumeric characters obey the following partial ordering:

```
A<B<C<D<E<F<G<H<I<J<K<L<M<N<O<P<Q<R<S<T<U<V<W<X<Y<Z
a<b<c<d<e<f<g<h<i<j<k<l<m<n<o<p<q<r<s<t<u<v<w<x<y<z
0<1<2<3<4<5<6<7<8<9
either 9<A or Z<0
either 9<a or z<0
```

This implies that alphabetic ordering holds, and that the digits as a group are not interleaved with letters, but that the possible interleaving of upper-case letters and lower-case letters is unspecified.

- If two characters have the same bits and font attributes, then their ordering by `char<` is consistent with the numerical ordering by the predicate < (page 150) on their code attributes.

`char-lessp` *char1 char2* [*Function*]

`char-greaterp` *char1 char2* [*Function*]

The arguments *char1* and *char2* must be character objects. The predicate `char-lessp` is like `char<`, except that it ignores differences of font and bits attributes and case; similarly `char-greaterp` is like `char>`. By definition,

```
(char-lessp c1 c2) <=>
      (char< (char-upcase (character c1))
             (char-upcase (character c2)))
```

15.2. Character Construction and Selection

`character` *object* [*Function*]

The function `character` coerces its argument to be a character if possible. If the argument is a character, the argument is simply returned. If the argument is a string of length 1, then the sole element of the string is returned. If the argument is a symbol whose print name is of length 1, then the sole element of the print name is returned. If the argument is an integer *n*, then (`int-char` *n*) is returned.

??? Query: This definition is more restrictive than the Lisp Machine Lisp version. Should it be loosened?

`char-code` *char* [*Function*]

The argument *char* must be a character object. `char-code` returns the *code* attribute of the character object; this will be a non-negative integer less than the (normal) value of the variable `char-code-limit` (page 173).

`char-bits` *char* [*Function*]

The argument *char* must be a character object. `char-bits` returns the *bits* attribute of the character object; this will be a non-negative integer less than the (normal) value of the variable `char-bits-limit` (page 173).

`char-font` *char* [*Function*]

The argument *char* must be a character object. `char-font` returns the *font* attribute of the character object; this will be a non-negative integer less than the (normal) value of the variable `char-font-limit` (page 173).

`code-char` *code* `&optional` (*bits* `0`) (*font* `0`) [*Function*]

All three arguments must be non-negative integers. If it is possible in the implementation to construct a character object whose code attribute is *code*, whose bits attribute is *bits*, and whose font attribute is *font*, then such an object is returned; otherwise `()` is returned.

For any integers *c*, *b*, and *f*, if (`code-char` *c b f*) is not `()` then

```
(char-code (code-char c b f)) => c
(char-bits (code-char c b f)) => b
(char-font (code-char c b f)) => f
```

If the font and bits attributes of a character object *x* are zero, then it is the case that

```
(char= (code-char (char-code c)) c)
```

is true

`make-char` *code* `&optional` (*bits* `0`) (*font* `0`) [*Function*]

The arguments *code*, *bits*, and *font* must be non-negative integers. If it is possible in the implementation to construct a character object whose code attribute is *code*, whose bits attribute is *bits*, and whose font attribute is *font*, then such an object is returned; otherwise `()` is returned.

If *bits* and *font* are zero, then `make-char` cannot fail. This implies that for every character object one can "turn off" its bits and font attributes.

15.3. Character Conversions

`char-upcase` *char* [*Function*]

`char-downcase` *char* [*Function*]

The argument *char* must be a character object. `char-upcase` attempts to convert its argument to an upper-case equivalent; `char-downcase` attempts to convert to lower case.

`char-upcase` returns a character object with the same font and bits attributes as *char*, but with possibly a different code attribute. If the code is different from *char*'s, then the predicate `lowercasep` (page 174) is true of *char*, and `uppercasep` (page 174) is true of the result character. Moreover, if (`char= (char-upcase x) x`) is *not* true, then it is true that

```
(char= (char-downcase (char-upcase x)) x)
```

Similarly, `char-downcase` returns a character object with the same font and bits attributes as *char*, but with possibly a different code attribute. If the code is different from *char*'s, then the predicate `uppercasep` (page 174) is true of *char*, and `lowercasep` (page 174) is true of the result character. Moreover, if (`char= (char-downcase x) x`) is *not* true, then it is true that

```
(char= (char-upcase (char-downcase x)) x)
```

`digit-charp` *weight* `&optional` (*radix* `10.`) (*bits* `0`) (*font* `0`) [*Function*]
`digit-weight` *weight* `&optional` (*radix* `10.`) (*bits* `0`) (*font* `0`) [*Function*]

All arguments must be integers. `digit-charp` determines whether or not it is possible to construct a character object whose bits attribute is *bits*, whose font attribute is *font*, and whose *code* is such that the result character has the weight *weight* when considered as a digit of the radix *radix* (see the predicate `digitp` (page 175)). It returns `t` if that is possible, and otherwise returns `()`.

`digit-charp` cannot return `()` if *bits* and *font* are zero, *radix* is between 2 and 36 inclusive, and *weight* is non-negative and less than *radix*.

`digit-weight` assumes that its arguments satisfy `digit-charp`, and constructs such a character. If more than one character object can encode such a weight in the given radix, one shall be chosen consistently by any given implementation; moreover, among the standard characters upper-case letters are preferred to lower-case letters).

For example:

```
(digit-char 7) => #\7
(digit-char 12) => ()
(digit-char 12 16) => #\C          ;not #\c
(digit-char 6 2) => ()
(digit-char 1 2) => #\1
```

`char-int` *char* [*Function*]

The argument *char* must be a character object. `char-int` returns a non-negative integer encoding the character object.

If the font and bits attributes of *char* are zero, then `char-int` returns the same integer `char-code` would. Also,

```
(char= c1 c2) <=> (= (char-int c1) (char-int c2))
```

for characters `c1` and *c2*.

This function is provided primarily for the purpose of hashing characters. Also, the function `tyi` (page 199) is defined in terms of `char-int`.

`int-char` *integer* [*Function*]

The argument must be a non-negative integer. `int-char` returns a character object `c` such that `(char-int c)` is equal to *integer*, if possible; otherwise `int-char` is false.

`char-name` *char* [*Function*]

The argument *char* must be a character object. If the character has a name, then that name (a symbol) is returned; otherwise `()` is returned. All characters which have zero font and bits attributes and which are non-graphic (do not satisfy the predicate `graphicp` (page 174)) have names. Graphic characters may or may not have names.

The standard characters <return> and <space> have the respective names `return` and `space`. The

optional characters <tab>, <form>, <rubout>, <linefeed>, and <backspace> have the respective names `tab`, `form`, `rubout`, `linefeed`, and `backspace`.

Characters which have names can be notated as "`#\`" followed by the name: `#\Space`.

`name-char` *sym* [*Function*]

The argument `sym` must be a symbol. If the symbol is the name of a character object, that object is returned; otherwise ( ) is returned.

15.4. Character Control-Bit Functions

COMMON LISP provides explici t names for four bits of the bits attribute: *Control*, *Meta*, *Hyper*, and *Super*. The following definitions are provided for manipulating these. Each COMMON LISP implementation provides these functions for compatibility, even if it does not support any or all of the bits named below.

`char-control-bit` [*Variable*]
`char-meta-bit` [*Variable*]
`char-super-bit` [*Variable*]
`char-hyper-bit` [*Variable*]

The initial values of these variables are the "weights" for the four named control bits. The weight of the control bit is `1`; of the meta bit, `2`; of the super bit, `4`; and of the hyper bit, `8`.

If a given implementation of COMMON LISP does not support a particular bit, then the corresponding variable is zero instead.

`char-bit` *char name* [*Function*]

`char-bit` takes a character object *char* and the name of a bit, and returns non-( ) if the bit of that name is set in *char*, or ( ) if the bit is not set in *char*. Valid values for *name* are implementation-dependent, but typically are `:control`, `:meta`, `:hyper`, and `:super`.

For example:

```
(char-bit #\Control-X ':control) => true
```

`set-char-bit` *char name newvalue* [*Function*]

`char-bit` takes a character object *char*, the name of a bit, and a flag. A character is returned which is just like *char* except that the named bit is set or reset according to whether *newvalue* is non-( ) or ( ). Valid values for *name* are implementation-dependent, but typically are `:control`, `:meta`, `:hyper`, and `:super`.

For example:

```
(set-char-bit #\X ':control t) => #\Control-X
(set-char-bit #\Control-X ':control t) => #\Control-X
(set-char-bit #\Control-X ':control ()) => #\X
```

Chapter 16

Strings

A string is a specialized kind of vector whose elements are characters. While, strictly speaking, only vectors of characters are called strings (as opposed to all arrays of characters), the string operations described here will operate properly on any one-dimensional array of characters.

> **Compatibility note:** Lisp Machine LISP allows a fixnum to be coerced into a one-character string whose element is a character whose ASCII value is the fixnum. The net effect is that a single character can be automatically coerced to be a one-character string. It would be inconsistent with adherence to the character standard, and possibly also affect efficiency adversely in some implementations, to remain compatible with this.

As a rule, any string operation will accept a symbol instead of a string as an argument if the operation never modifies that argument; the print-name of the symbol is used. In this respect the string-specific sequence operations are not simply specializations of the generic versions; the generic sequence operations never accept symbols as sequences. This slight inelegance is permitted in COMMON LISP in the name of pragmatic utility. Also, there is a slight non-parallism in the names of string functions. Where the suffixes `equalp` and `eql` would be more appropriate, for historical compatibility the suffixes `equal` and `=` are used instead to indicate case-insensitive and case-sensitive character comparison, respectively.

Any LISP object may be tested for being a string by the predicate `stringp` (page 38).

16.1. String Access and Modification

`char` *string index* [*Function*]

The given *index* must be a non-negative integer less than the length of *string*. The character at position *index* of the string is returned as a character object. (This character will necessarily satisfy the predicate `string-charp` (page 174).) As with all sequences in COMMON LISP, indexing is zero-origin.

For example:

```
(char "Floob-Boober-Bab-Boober-Bubs" 0) => #\F
(char "Floob-Boober-Bab-Boober-Bubs" 1) => #\l
```

See `elt` (page 88).

`rplachar` *string index newchar* [*Function*]

The argument *string* must be a string. The given *index* must be a non-negative integer less than the length of the string. The character at position *index* is altered to be *newchar*, which must be a character object which satisfies the predicate `string-charp` (page 174). `rplachar` returns *newchar* as its value. See `setelt` (page 88).

16.2. String Comparison

`string=` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]

`string=` compares two strings, and is true if they are the same (corresponding characters are identical) but is false if they are not. The function `equal` (page 40) calls `string=` if applied to two strings.

The optional arguments *start1* and *start2* are the places in the strings to start the comparison. The optional arguments *end1* and *end2* places in the strings to stop comparing; comparison stops just *before* the position specified by a limit. The *start* arguments default to zero (beginning of string), and the *end* arguments (if either omitted or ( )) default to the lengths of the strings (end of string), so that by default the entirety of each string is examined. These arguments are provided so that substrings can be compared efficiently.

`string=` is necessarily false if the (sub)strings being compared are of unequal length; that is, if

```
(not (= (- end1 start1) (- end2 start2)))
```

is true then `string=` is false.

For example:

```
(string= "foo" "foo") is true
(string= "foo" "Foo") is false
(string= "foo" "bar") is false
(string= "together" "frogs" 1 2 3 4) is true
```

`string-equal` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]

`string-equal` is just like `string=` except that differences in case are ignored; two characters are considered to be the same if `char-equal` (page 176) is true of them.

For example:

```
(string-equal "foo" "Foo") is true
```

`string<` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string>` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string<=` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string>=` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string/=` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]

The two string arguments are compared lexicographically, and the result is ( ) unless *string1* is (less

than, greater than, less than or equal to, greater than or equal to, not equal to) *string2*, respectively. If the condition is satisfied, however, then the result is the index within the strings of the first character position at which the strings fail to match; put another way, the result is the length of the longest common prefix of the strings.

A string *a* is less than a string *b* if in the first position in which they differ the character of *a* is less than the corresponding character of *b* according to the function `char<` (page 176), or if string *a* is a proper prefix of string *b* (of shorter length and matching in all the characters of *a*).

The optional arguments *start1* and *start2* are the places in the strings to start the comparison. The optional arguments *end1* and *end2* places in the strings to stop comparing; comparison stops just *before* the position specified by a limit. The *start* arguments default to zero (beginning of string), and the *end* arguments (if either omitted or ( )) default to the lengths of the strings (end of string), so that by default the entirety of each string is examined. These arguments are provided so that substrings can be compared efficiently. The index returned in case of a mismatch is an index into *string1*.

`string-lessp` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string-greaterp` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string-not-lessp` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string-not-greaterp` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]
`string-not-equal` *string1 string2* `&optional` *start1 end1 start2 end2* [*Function*]

These are exactly like `string<`, `string>`, `string<=`, `string>=`, and `string<>`, respectively, except that distinctions between upper-case and lower-case letters are ignored. It is if `char-lessp` (page 177) were used instead of `char<` (page 176) for comparing characters.

16.3. String Construction and Manipulation

`make-string` *count* `&optional` *fill-character* [*Function*]

This returns a string of length *count*, each of whose characters has been initialized to the *fill-character*. If *fill-character* is not specified, then the string will be initialized in an implementation-dependent way.

Implementation note: It may be convenient to initialize the string to null characters, or to spaces, or to garbage ("whatever was there").

`string-trim` *character-bag string* [*Function*]
`string-left-trim` *character-bag string* [*Function*]
`string-right-trim` *character-bag string* [*Function*]

`string-trim` returns a substring (in the sense of the function `substring` (page SUBSTRING-FUN)) of *string*, with all characters in *character-bag* stripped off of the beginning and end. The function `string-left-trim` is similar, but strips characters off only the beginning; `string-right-trim` strips off only the end. The argument *character-bag* may be a

list of characters or a string.

For example:

```
(string-trim '(#\Space #\Tab #\Return) " garbanzo beans
        ") => "garbanzo beans"
(string-trim " ()*" " ( *three (silly) words* ) ")
   => "three (silly) words"
(string-left-trim " ()*" " ( *three (silly) words* ) ")
   => "three (silly) words* ) "
(string-right-trim " ()*" " ( *three (silly) words* ) ")
   => " ( *three (silly) words"
```

`string-upcase` *string* [*Function*]
`string-downcase` *string* [*Function*]
`string-capitalize` *string* [*Function*]

`string-upcase` returns a string just like *string* with all lower-case alphabetic characters replaced by the corresponding upper-case characters. More precisely, each character of the result string is produced by applying the function `char-upcase` (page 178) to the corresponding character of *string*.

`string-downcase` is similar, except that upper-case characters are converted to lower-case characters (using `char-downcase` (page 178)).

The argument is not destroyed. However, if no characters in the argument require conversion, the result may be either the argument or a copy of it, at the implementation's discretion.

For example:

```
(string-upcase "Dr. Livingston, I presume?")
   => "DR. LIVINGSTON, I PRESUME?"
(string-downcase "Dr. Livingston, I presume?")
   => "dr. livingston, i presume?"
```

`string-capitalize` produces a copy of *string* such that every word (subsequence of case-modifiable characters delimited by non-case-modifiable characters) has its first character in upper-case and any other letters in lower-case.

For example:

```
(string-capitalize " hello ") => " Hello "
(string-capitalize
    "occlUDeD cASEmenTs FOreSTAll iNADVertent DEFenestraTION")
 => "Occluded Casements Forestall Inadvertent Defenestration"
(string-capitalize 'kludgy-hash-search) => "Kludgy-Hash-Search"
```

16.4. Type Conversions on Strings

`string` *x* [*Function*]

`string` coerces *x* into a string. Most of the string functions apply this to such of their arguments as are supposed to be strings. If *x* is a string, it is returned. If *x* is a symbol, its print-name is returned. If *x* cannot be coerced to be a string, an error occurs.

To get the string representation of a number or any other LISP object, use `prinstring` (page PRINSTRING-FUN) or `format` (page 203).

Chapter 17

Arrays

17.1. Array Creation

`make-array` *dimensions* `&rest` *options* [*Function*]

This is the primitive function for making arrays. *dimensions* should be a list of non-negative integers (in fact, fixnums) which are the dimensions of the array; the length of the list will be the dimensionality of the array. For convenience when making a one-dimensional array, the single dimension may be provided as an integer rather than a list of one integer.

There must be an even number of *options* arguments; they are alternating keywords and values, each keyword having one associated value. Valid keywords are:

`:type` The value should be the name of the type of the elements of the array; an array is constructed of the most specialized type which can nevertheless accommodate elemments of the given type. The type `t` specifies a general array, one whose elements may be any LISP object; this is the default type.

`:initial-value`
The value is used to initialize each element of the array. The value must be of the type specified by the `:type` option. If the `:initial-value` option is omitted, the initial values of the array elements are undefined (unless the `:displaced-to` option is used). The `:initial-value` option may not be used with the `:displaced-to` option.

`:fill-pointer`
This option specifies that the array should have a fill pointer. If this option is specified, the array must be one-dimensional. The value is used to initialize the fill pointer for the array. if the value ( ) is specified, the length of the array is used; otherwise the value must be an integer between 0 (inclusive) and the length of the array (inclusive).

`:displaced-to`
If the value is not ( ), then the array will be a *displaced* array. The value must be an array or vector; `make-array` will create an *indirect* or *shared* array which shares its contents with the specified array. In this case the `:displaced-index-offset` option may be useful. The `:displaced-to` option may not be used with the `:initial` option.

`:displaced-index-offset`
If this is present, the value of the `:displaced-to` option should be an array, and the value of this option should be a non-negative fixnum; it is made to be the index-offset of the created shared array.

`:extendable` The argument is a flag, which if non-`()` (the default) specifies that the array may have its size altered by the functions `adjust-array-size` and `array-grow`. Even if the flag is `()`, however, the array may be made smaller by `adjust-array-size` if the array is one-dimensional.

If the array is one-dimensional, the `:fill-pointer` and `:displaced-to` keywords are not specified, and `:extendable ()` is specified, then the array returned will in fact be a vector.

Compatibility note: The Lisp Machine LISP `:area` and `:named-structure-symbol` keywords are omitted here, and `:initial-value` and `:fill-pointer` are new.

For example:

```
;; Create a one-dimensional array of five elements.
(make-array 5)

;; Create a two-dimensional array, 3 by 4, with four-bit elements.
(make-array '(3 4) ':type '(mod 16))

;; Create an array of single-floats.
(make-array 5 ':type ':single-float))

;; Making a shared array.
(setq a (make-array '(4 3)))
(setq b (make-array 8 ':displaced-to a
                      ':displaced-index-offset 2))
;;Now it is the case that:
        (aref b 0) <=> (aref a 0 2)
        (aref b 1) <=> (aref a 1 0)
        (aref b 2) <=> (aref a 1 1)
        (aref b 3) <=> (aref a 1 2)
        (aref b 4) <=> (aref a 2 0)
        (aref b 5) <=> (aref a 2 1)
        (aref b 6) <=> (aref a 2 2)
        (aref b 7) <=> (aref a 3 0)
```

The last example depends on the fact that arrays are, in effect, stored in row-major order for purposes of sharing. Put another way, the sequences of indices for the elements of an array are ordered lexicographically.

Compatibility note: Both Lisp Machine LISP and FORTRAN store arrays in column-major order.

17.2. Array Access

`aref` *array* `&rest` *subscripts* [*Function*]

This accesses and returns the element of *array* specified by the *subscripts*. The number of subscripts must equal the rank of the array, and each subscript must be a non-negative integer less than the corresponding array dimension.

`aset` *new-value array* `&rest` *subscripts* [*Function*]

This stores *new-value* into the element of *array* specified by the *subscripts*. The number of subscripts must equal the rank of the array, and each subscript must be a non-negative integer less than the corresponding array dimension. The result of `aset` is the value *new-value*.

The argument *new-value* must be of a type suitable for storing into *array* if the *array* is of a specialized type.

17.3. Array Information

`array-type` *array* [*Function*]

This returns the type of elements of the array. For a general array, this is `t`; for an array of eight-bit integers, `(mod 256)` might be returned. What is returned is the actual type of the array elements, which may be the same as that specified to `make-array`, or may be more general if the implementatation doesn't support arrays of that specific type.

`array-length` *array* [*Function*]

array may be any array. This returns the total number of elements allocated in *array*. For a one-dimensional array, this is equal to the length of the single axis. (If a fill pointer is in use for the array, however, the function `array-active-length` (page 161) may be more useful.)

`array-active-length` *array* [*Function*]

`array-active-length` returns the fill pointer for the array. This is normally the same as the length of the array unless `reset-fill-pointer` (page RESET-FILL-POINTER-FUN) has been used.

`array-rank` *array* [*Function*]

Returns the number of dimensions (axes) of *array*. This will be a non-negative integer.

> Compatibility note: In Lisp Machine LISP this is called `array-#-dims`. This name causes problems in MACLISP because of the # character. The problem is better avoided.

`array-dimension` *axis-number array* [*Function*]

The length of dimension number *axis-number* of the *array* is returned. *array* may be any kind of array, and *axis-number* should be a non-negative integer less than the rank of *array*.

> Compatibility note: This is similar to the Lisp Machine LISP function `array-dimension-n`, but is zero-origin for consistency instead of one-origin. Also, in Lisp Machine LISP `(array-dimension-n 0)` returns the length of the array leader.

`array-dimensions` *array* [*Function*]

`array-dimensions` returns a list whose elements are the dimensions of *array*.

`array-in-bounds-p` *array* `&rest` *subscripts* [*Function*]

This predicate checks whether the *subscripts* are all legal subscripts for *array*, and is true if they are; otherwise it is false. The *subscripts* must be integers. There must be as many subscripts as rank of array.

17.4. Functions on General Vectors (Vectors of LISP Objects)

The functions in this section are equivalent in operation to the corresponding more general functions, but require arguments to be vectors of type `(vector t)`. These functions are provided primarily for reasons of efficiency and convenience. ↑ Scott sez: any vectors.

`vref` *vector index* [*Function*]

The element of the *vector* specified by the integer *index* is returned. The *index* must be non-negative and less than the length of the vector. See `elt` (page 88) and `aref` (page 188).

`vset` *vector index newvalue* [*Function*]

The LISP object *newvalue* is stored into the component of the *vector* specified by the integer *index*. The *index* must be non-negative and less than the length of the vector. See `setelt` (page 88) and `aset` (page 189).

17.5. Functions on Bit-Strings

`bit` *bit-string index* [*Function*]

The element of the *bit-string* specified by the integer *index* is returned. The *index* must be non-negative and less than the length of the vector. The result will always be `0` or `1`. See `elt` (page 88).

`rplacbit` *bit-string index newbit* [*Function*]

The *newbit* is stored into the component of the *bit-string* specified by the integer *index*. The *index* must be non-negative and less than the length of the vector. The *newvalue* must be `0` or `1`. See `setelt` (page 88).

`bit-and` `&rest` *bit-strings* [*Function*]
`bit-ior` `&rest` *bit-strings* [*Function*]
`bit-xor` `&rest` *bit-strings* [*Function*]
`bit-eqv` `&rest` *bit-strings* [*Function*]
`bit-nand` *bit-string1 bit-string2* [*Function*]

`bit-nor` *bit-string1 bit-string2* [*Function*]
`bit-andc1` *bit-string1 bit-string2* [*Function*]
`bit-andc2` *bit-string1 bit-string2* [*Function*]
`bit-orc1` *bit-string1 bit-string2* [*Function*]
`bit-orc2` *bit-string1 bit-string2* [*Function*]

These functions perform bit-wise logical operations on bit-strings. All of the arguments to any of these functions must be bit-strings or one-dimensional arrays of bits, all of the same length. The result is a bit-string matching the argument(s) in length, such that bit *j* of the result is produced by operating on bit *j* of each of the arguments. Indeed, if the arguments are in fact bit-strings of the same length, then

`(bit-`*xxx* . *arguments*`) <=> (bit-map #'log`*xxx* . *arguments*`)`

That is, each `bit-` function described here is simply a mapping over bit-strings of a `log` function which applies to integers (and therefore to the bit values 0 and 1).

The following table indicates what the result bit is for each operation when two arguments are given. (Those operations which accept an indefinite number of arguments are commutative and associative, and require at least one argument.)

Argument 1	0	1	0	1	
Argument 2	0	0	1	1	*Operation name*
`bit-and`	0	0	0	1	and
`bit-ior`	0	1	1	1	inclusive or
`bit-xor`	0	1	1	0	exclusive or
`bit-eqv`	1	0	0	1	equivalence (exclusive nor)
`bit-nand`	1	1	1	0	not-and
`bit-nor`	1	0	0	0	not-or
`bit-andc1`	0	1	0	0	and complement of arg1 with arg2
`bit-andc2`	0	0	1	0	and arg1 with complement of arg2
`bit-orc1`	1	1	0	1	or complement of arg1 with arg2
`bit-orc2`	1	0	1	1	or arg1 with complement of arg2

`bit-not` *bit-string* [*Function*]

The argument must be a one-dimensional array of bits. A bit-string containing a copy of the argument with all the bits inverted is returned. That is, bit *j* of the result is 1 iff bit *j* of the argument is zero.

`(bit-not` *bitvec*`) <=> (bit-map #'lognot` *bitvec*`)`

17.6. Fill Pointers

To make it easy to incrementally fill in the contents of an array, a set of functions for manipulating a *fill pointer* are defined. The fill pointer is a non-negative integer no larger than the total number of elements in the array (as returned by `array-length` (page 189)); it is the number of "active" or "filled-in" elements in the array. When an array is created, its fill pointer is initialized to the number of elements in the array; the fill

pointer should be *reset* before use. The fill pointer constitutes the "active length" of the array. Some functions will ignore elements beyond the fill-pointer index; those that do are so documented.

Multidimensional arrays may have fill pointers; elements are filled in row-major order (last index varies fastest).

`array-reset-fill-pointer` *array* `&optional` *index* [*Function*]

The fill pointer of *array* is reset to *index*, which defaults to zero. The *index* must be a non-negative integer not greater than the old value of the fill pointer.

`array-push` *array new-element* [*Function*]

array must be a one-dimensional array which has a fill pointer, and *new-element* may be any object. `array-push` attempts to store *new-element* in the element of the array designated by the fill pointer, and increase the fill pointer by one. If the fill pointer does not designate an element of the array (specifically, when it gets too big), it is unaffected and `array-push` returns `()`. Otherwise, the store and increment take place and `array-push` returns the *former* value of the fill pointer (one less than the one it leaves in the array); thus the value of `array-push` is the index of the new element pushed.

`array-push-extend` *array x* `&optional` *extension* [*Function*]

`array-push-extend` is just like `array-push` except that if the fill pointer gets too large, the array is extended (using `adjust-array-size` (page 163)) so that it can contain more elements; it never "fails" the way `array-push` does, and so never returns `()`. The optional argument *extension*, which must be a positive integer, is the minimum number of elements to be added to the array if it must be extended.

`array-pop` *array* [*Function*]

array must be a one-dimensional array which has a fill pointer. The fill pointer is decreased by one, and the array element designated by the new value of the fill pointer is returned. If the new value does not designate any element of the array (specifically, if it has reached zero), an error occurs.

17.7. Changing the Size of an Array

`adjust-array-size` *array new-size* `&optional` *new-element* [*Function*]

The *array* is adjusted so that it contains (at least) *new-size* elements. The argument *new-size* must be a non-negative integer.

If *array* is a one-dimensional array, its size is simply changed to be *new-size*, by altering its single dimension. If *array* has more than one dimension, then its *first* dimension is adjusted to the smallest possible value which allows the array to have no fewer than *new-size* elements. There are two degenerate cases, however:

1. If any dimension other than the first is zero, then the array is not changed, and an error occurs if *new-size* is not 0.

2. If the array has zero dimensions, then the array is not changed, and an error occurs if *new-size* is not 0 or 1.

If *array* is made smaller, the extra elements are lost. If *array* is made bigger, the new elements are initialized to *new-element*; if this argument is not provided, then the values of the new elements are undefined.

`adjust-array-size` may, depending on the implementation and the arguments, simply alter the given array or create and return a new one. In the latter case the given array will be altered so as to be displaced to the new array and have the given new dimensions.

If `adjust-array-size` is applied to an array created with the `:displaced-to` (page 187) option, or to an array used as the argument for the `:displaced-to` option in the creation of another array, then the operation will be performed correctly with respect to the given array, but the effects on the other array will be unpredictable.

Compatibility note: In Lisp Machine Lisp, the argument *new-element* is not provided; it would seem useful, however.

Also the Lisp Machine Lisp manual is unclear on the precise method of extension for multidimensional arrays. The above definition ties this down.

`array-grow` *array new-element* `&rest` *dimensions* [*Function*]

`array-grow` returns an array of the same type as *array*, with the specified *dimensions*. The number of *dimensions* given must equal the rank of *array*.

Those elements of *array* that are still in bounds appear in the new array. The elements of the new array that are not in the bounds of *array* are initialized to *new-element*; if this argument is not provided, then the initial contents of any new elements are undefined.

`array-grow` may, depending on the implementation and the arguments, simply alter the given array or create and return a new one. In the latter case the given array will be altered so as to be displaced to the new array and have the given new dimensions.

If `array-grow` is applied to an array created with the `:displaced-to` (page 187) option, or to an array used as the argument for the `:displaced-to` option in the creation of another array, then the operation will be performed correctly with respect to the given array, but the effects on the other array will be unpredictable.

`array-grow` differs from `adjust-array-size` in that it keeps the elements of a multidimensional array in the same logical positions while allowing extension of any or all dimensions, not just the first.

Chapter 18

Structures

COMMON LISP provides a facility for creating named record structures with named components. In effect, the user can declare a new data type; every data structure of that type has components with specified names. Constructor, access, and assignment constructs are automatically defined when the data type is declared.

This chapter is divided into two parts. The first part discusses the basics of the structure facility, which is very simple and allows the user to take advantage of the type-checking, modularity, and convenience of user-defined record data types. The second part discusses a number of specialized features of the facility which have advanced applications. These features are completely optional, and you needn't even know they exist in order to take advantage of the basics.

> **Rationale:** It is important not to scare the novice away from `defstruct` with a multiplicity of features. The basic idea is very simple, and we should encourage its use by providing a very simple description. The hairy stuff, including all options, is shoved to the end of the chapter.

18.1. Introduction to Structures

The structure facility is embodied in the `defstruct` macro, which allows the user to create and use aggregate datatypes with named elements. These are like "structures" in PL/I, or "records" in PASCAL.

As an example, assume you are writing a LISP program that deals with space ships in a two-dimensional plane. In your program, you need to represent a space ship by a LISP object of some kind. The interesting things about a space ship, as far as your program is concerned, are its position (represented as x and y coordinates), velocity (represented as components along the x and y axes), and mass.

A ship might therefore be represented as a record structure with five components: x-position, y-position, x-velocity, y-velocity, and mass. This structure could in turn be implemented as a LISP object in a number of ways. It could be a list of five elements; the x-position could be the *car*, the y-position the *cadr*, and so on. Equally well it could be a vector of five elements: the x-position could be element 0, the y-position element 1, and so on. The problem with either of these representations is that the components occupy places in the object which are quite arbitrary and hard to remember. Someone looking at `(cadddr ship1)` or `(vref ship1 3)` in a piece of code might find it difficult to determine that this is accessing the y-velocity component of `ship1`. Moreover, if the representation of a ship should have to be changed, it would be very

difficult top find all the places in the code to be changed to match (not all occurrences of `cadddr` are intended to extract the *y*-velocity from a ship).

Ideally components of record structures should have names. One would like to write something like `(ship-y-velocity ship1)` instead of `(cadddr ship1)`. One would also like a more mnemonic way to create a ship than this:

```
(list 0 0 0 0 0)
```

Indeed, one would like `ship` to be a new data type, just like other LISP data types, that one could test with `typep` (page 36), for example. The `defstruct` facility provides all of this.

`defstruct` itself is a macro which defines a structure. For the space ship example one we might define the structure by saying:

```
(defstruct ship
  ship-x-position
  ship-y-position
  ship-x-velocity
  ship-y-velocity
  ship-mass)
```

This declares that every `ship` is an object with five named components. The evaluation of this form does several things:

- It defines `ship-x-position` to be a function of one argument, a ship, which returns its *x*-position; `ship-y-position` and the other components are given similar function definitions. These functions are called the *access functions*, as they are used to access elements of the structure.

- The symbol `ship` becomes the name of a data type, of which instances of ships are elements. This name becomes acceptable to `typep` (page 36), for example; `(typep x 'ship)` is true iff `x` is a ship. Moreover, all ships are instances of the type `structure`, because `ship` is a subtype of `structure`.

- A function named `ship-p` of one argument is defined; it is a predicate which is true if its argument is a ship, and is false otherwise.

- A macro called `make-ship` is defined which, when invoked, will create a data structure with five components, suitable for use with the access functions. Thus executing

  ```
  (setq ship2 (make-ship))
  ```

  sets `ship2` to a newly-created `ship` object. One can specify the initial values of any desired component in the call to `make-ship` in this way:

  ```
  (setq ship2 (make-ship ship-mass *default-ship-mass*
                         ship-x-position 0
                         ship-y-position 0))
  ```

  This constructs a new ship and initializes three of its components. This macro is called the *constructor macro*, because it constructs a new structure.

- Two ways are provided to alter components of a `ship`. One way is to use the macro `setf` (page 50) in conjunction with an access function (because `defstruct` performs an appropriate

`defsetf` (page DEFSETF-FUN)):

```
(setf (ship-x-position ship2) 100)
```

This alters the *x*-position of *ship2* to be 100. This works because `defstruct` generates an appropriate `defsetf` (page DEFSETF-FUN) form for each access function.

The other way is to use the special *alterant macro*, which allows alteration of several components at once in parallel:

```
(alter-ship enterprise                ;Counter-clockwise inter-quadrant warp!
            ship-x-position (- (ship-y-position enterprise))
            ship-y-position (ship-x-position enterprise))
```

Besides allowing parallel updating of several components, use of the alterant macro may be more efficient in certain cases.

This simple example illustrates the power of `defstruct` to provide abstract record structures in a convenient manner. `defstruct` has many other features as well for specialized purposes.

18.2. How to Use Defstruct

`defstruct` *name-and-options* {*slot-description*}+ [*Macro*]

Defines a record-structure data type. A general call to `defstruct` looks like this:

```
(defstruct (name option-1 option-2 ...)
           slot-description-1
           slot-description-2
           ...)
```

name must be a symbol; it becomes the name of a new data type consisting of all instances of the structure. The function `typep` (page 36) will accept and use this name as appropriate.

Usually no options are needed at all. If no options are specified, then one may write simply *name* instead of (*name*) after the word `defstruct`. The syntax of options and the options provided are discussed in section ???.

Each *slot-description-j* is of the form

(*slot-name default-init slot-option-1 slot-option-2 ...*)

Each *slot-name* must be a symbol; an access function is defined for each slot. If no options and no *default-init* are specified, then one may write simply *slot-name* instead of (*slot-name*) as the slot description. The *default-init* is a form which is evaluated *each time* a structure is to be constructed; the value is used as the initial value of the slot. If no *default-init* is specified, then the initial contents of the slot are undefined and implementation-dependent. The available slot-options are described in section ???.

Compatibility note: Slot-options are not currently provided in Lisp Machine Lisp, but this is an upward-compatible extension.

Besides defining an access function for each slot, `defstruct` arranges for `setf` to work properly on such access functions, defines a predicate named *name*`-p`, and defines constructor and alterant

macros named `make-`*name* and `alter-`*name*, respectively.

Because evaluation of a `defstruct` form causes many functions and macros to be defined, one must take care that two `defstruct` forms do not define the same name (just as one must take care not to use `defun` to define two distinct functions of the same name). For this reason, as well as for clarity in the code, it is conventional to prefix the names of all of the slots with some text which identifies the structure. In the example above, all the slot names start with "`ship-`". The `:conc-name` (page 170)option can be used to provide such prefixes automatically.

18.3. Using the Automatically Defined Macros

After you have defined a new structure with `defstruct`, you can create instances of this structure by using the constructor macro, and alter the values of its slots by using the alterant macro. By default, `defstruct` defines these macros automatically, forming their names by adding prefixes to the name of the structure; for a structure named `foo`, the respective macro names would be `make-foo` and `alter-foo`. You can specify the names yourself by giving the name you want to use as the argument to the `:constructor` (page 172) and `:alterant` (page 172) options, or specify that you don't want a macro created at all by using ( ) as the argument.

18.3.1. Constructor Macros

A call to a constructor macro, in general, has the form

```
( name-of-constructor-macro
        slot-name-1  form-1
        slot-name-2  form-2
        ...)
```

Each *slot-name* should be the name of a slot of the structure. All the *forms* are evaluated.

If *slot-name-j* is the name of a slot, then that element of the created structure will be initialized to the value of *form-j*. If no *slot-name-j*/*form-j* pair is present for a given slot, then the slot will be initialized by evaluating the *default-init* form specified for that slot in the call to `defstruct`. (In other words, the initialization specified in the `defstruct` defers to any specified in a call to the constructor macro.) If the default initialization form is used, it is evaluated at construction time, but in the lexical environment of the `defstruct` form in which it appeared. If the `defstruct` itself also did not specify any initialization, the element's initial value is undefined. You should always specify the initialization, either in the `defstruct` or in the constructor macro, if you care about the initial value of the slot.

Compatibility note: The Lisp Machine Lisp documentation is slightly unclear about when the initialization specified in the `defstruct` form gets evaluated: at `defstruct` evaluation time, or at constructor time? The code reveals that it is at constructor time, which causes problems with referential transparency with respect to lexical variables (which currently don't exist officially in Lisp Machine Lisp anyway). The above remark concerning the lexical environment in effect requires that the initialization form is treated as a thunk; it is evaluated at constructor time, but in the environment where it was written (the `defstruct` environment). Most of the time this makes no difference anyway, as the initialization form is typically a quoted constant or refers only to special variables. The requirement is imposed here for uniformity, and to ensure that what look like special variable references in the initialization form are in fact always treated as such.

The order of evaluation of the initialization forms is *not* necessarily the same as the order in which they appear in the constructor call or in the `defstruct` form; code should not depend on the order of evaluation. The initialization forms *are* re-evaluated on every constructor-macro call, so that if, for example, the form `(gensym)` were used as an initialization form, either in the constructor-macro call or as the default form in the `defstruct` declaration, then every call to the constructor macro would call `gensym` once to generate a new symbol.

18.3.2. Alterant Macros

A call to the alterant macro, in general, has the form

(name-of-alterant-macro instance-form
slot-name-1 form-1
slot-name-2 form-2
...)

instance-form is evaluated, and should return an instance of the structure. Each *form-j* is evaluated, and the corresponding slot named by *slot-name-j* is changed to have the result as its new value. The assignments are parallel; that is, the slots are altered *after* all the *forms* have been evaluated, so you can exchange the values of two slots, as follows:

```
(alter-ship enterprise
    ship-x-position (ship-y-position enterprise)
    ship-y-position (ship-x-position enterprise))
```

As with the constructor macro, the order of evaluation of the *forms* is undefined.

Single slots can also be altered by using `setf` (page 50). Using the alterant macro may produce more efficient code than using consecutive `setf` forms.

18.4. `defstruct` Slot-Options

Each *slot-description* in a `defstruct` form may specify one or more slot-options. A slot-option may be a keyword, or a list of a keyword and arguments for that keyword.

For example:

```
(defstruct ship
  (ship-x-position 0.0 (:type :short-float))
  (ship-y-position 0.0 (:type :short-float))
  (ship-x-velocity 0.0 (:type :short-float) :invisible)
  (ship-y-velocity 0.0 (:type :short-float) :invisible)
  (ship-mass *default-ship-mass* :invisible :read-only))
```

specifies that the first four slots will always contain short-format floating-point numbers, that the last three slots are "invisible" (will not ordinarily be shown when a ship is printed), and that the last slot may not be altered once a ship is constructed.

The available slot-options are:

`:type` The option `(:type type)` specifies that the contents of the slot will always be of the

specified data type. This is entirely analogous to the declaration of a variable or function; indeed, it effectively declares the result type of the access function. An implementation may or may not choose to check the type of the new object when initializing or assigning to a slot.

`:invisible` The option `:invisible` specifies that the contents of this slot should not be printed when an instance of the structure is printed.

`:read-only` The option `:read-only` specifies that this slot may not be altered; it will always contain the value specified at construction time. The alterant macro will not accept the name of this slot, and `setf` (page 50) will not accept the access function for this slot.

18.5. Options to `defstruct`

The preceding description of `defstruct` is all that the average user will need (or want) to know in order to use structures. The remainder of this chapter discusses more complex features of the `defstruct` facility.

This section explains each of the options that can be given to `defstruct`. As with slot-options, a `defstruct` option may be either a keyword or a list of a keyword and arguments for that keyword.

`:conc-name` This provides for automatic prefixing of names of access functions. It is conventional to begin the names of all the access functions of a structure with a specific prefix, usually the name of the structure followed by a hyphen. If you do not use the `:conc-name` option, then the names of the access functions are the same as the slot names, and it is up to you to name the slots reasonably.

Specifying the `:conc-name` option causes each access functions to have a name consisting of a standard prefix followed by the name of the accessed slot. If the `:conc-name` option has an argument, it should be a string specifying the prefix, or a symbol whose print-name is the prefix. With no argument, the prefix is the name of the structure and a hyphen.

Note that in the constructor and alterant macros, you still use the slot names rather than the access function names. On the other hand, one uses the access-function name when using `setf`. Here is an example:

```
(defstruct (door :conc-name) knob-color width material)
(setq my-door (make-door knob-color 'red width 5.0))
(door-knob-color my-door) ==> red
(alter-door my-door  knob-color 'green  material 'wood)
(door-material my-door) => wood
(setf (door-width my-door) 43.7)
(door-width my-door) => 43.7
```

`:type` The `:type` option specifies what kind of LISP object will be used to implement the structure. It takes one argument, which must be one of the types enumerated below. If the `:type` option is not provided, the type defaults to `:vector`, and the `:named` option is assumed unless `:unnamed` is explicitly specified.

Rationale: Making a structure be `:unnamed` mostly just saves space. It is probably better to protect

the novice by providing by default a named vector, since that provides maximal features, nice printing, reasonable use of space (better than lists or arrays in most implementations), etc.

`:vector` Use a general vector, storing components as vector elements. This is normally `:named`.

`:array` Use a one-dimensional array, storing components in the body of the array. By default this is `:named`.

`(array` *type*`)` A specialized array may be used, in which case every component must be of a type which can be stored in such an array. The array must be one-dimensional.

Compatibility note: This is a suggested feature not yet in Lisp Machine LISP.

`:array-leader`
Make an object which is an array, and can be indexed as one, but which additionally has hidden `defstruct` components. By default this is `:named`. (See the option `:make-array` (page 173), described below.)

`:list` Use a list. A structure of this type cannot be distinguished by `typep`, even if the `:named` option is used. By default this is `:unnamed`.

`:integer` This unusual type implements the structure as a single integer. The structure may only have one slot. This is only useful with the byte field feature (see page DEFSTRUCT-BYTE-FIELD); it lets you store several small numbers within fields of an integer, giving the fields names. This cannot be `:named`.

Compatibility note: The `:integer` option is a suggested feature not yet in Lisp Machine LISP. It is similar to the `fixnum` option.

Compatibility note: All the "`named-`" types such as `:named-array` from Lisp Machine LISP have been omitted here, as they tend to multiply. An implementation may provide them, but they are not required here. The `:named` and `:unnamed` options may be used separately to get the same effect.

`:named` The `:named` option specifies that the structure is "named"; this option takes no argument. A named structure has an associated predicate for determining whether a given LISP object is a structure of that name. Some named structures in addition can be distinguished by the predicate `typep` (page 36). If neither `:named` nor `:unnamed` is specified, then the default depends on the `:type` option.

`:unnamed` The `:unnamed` option specifies that the structure is not named; this option takes no argument.

`:constructor`
This option takes one argument, a symbol, which specifies the name of the constructor macro. If the argument is not provided or if the option itself is not provided, the name of the constructor is produced by concatenating the string "`make-`" and the name of the structure. If the argument is provided and is `( )`, no constructor macro is defined.

This option actually has a more general syntax which is explained in ???.

`:alterant` This option takes one argument, which specifies the name of the alterant macro. If the argument is not provided or if the option itself is not provided, the name of the alterant macro is made by concatenating the string `"alter-"` to the name of the structure. If the argument is provided and is `()`, no alterant macro is defined. Use of the alterant macro is explained on ???.

`:predicate` This option takes one argument, which specifies the name of the type predicate. If the argument is not provided or if the option itself is not provided, the name of the predicate is made by concatenating the name of the structure to the string `"-p"`. If the argument is provided and is `()`, no predicate is defined. A predicate can be defined only if the structure is `:named` (page 201).

`:include` This option is used for building a new structure definition as an extension of an old structure definition. As an example, suppose you have a structure called `person` that looks like this:

```
(defstruct (person :conc-name)
   name
   age
   sex)
```

Now suppose you want to make a new structure to represent an astronaut. Since astronauts are people too, you would like them to also have the attributes of name, age, and sex, and you would like LISP functions that operate on `person` structures to operate just as well on `astronaut` structures. You can do this by defining `astronaut` with the `:include` option, as follows:

```
(defstruct (astronaut (:include person))
   helmet-size
   (favorite-beverage 'tang))
```

The `:include` option causes the structure being defined to have the same slots as the included structure, in such a way that the access functions and alterant macro for the included structure will also work on the structure being defined. In this example, an `astronaut` will therefore have five slots: the three defined in `person`, and the two defined in `astronaut` itself. The access functions defined by the `person` structure can be applied to instances of the `astronaut` structure, and they will work correctly. The following examples illustrate how you can use `astronaut` structures:

```
(setq x (make-astronaut name 'buzz
                        age 45.
                        sex t
                        helmet-size 17.5))

(person-name x) => buzz
(favorite-beverage x) => tang
```

Note that the `:conc-name` (page 200) option was *not* inherited from the included structure; it only applies to the names of the access functions of `person` and not to those of `astronaut`.

The argument to the `:include` option is required, and must be the name of some previously defined structure. The included structure must be of the same `:type` as this structure. The structure name of the including structure definition becomes the name of a data type, of course; moreover, it becomes a subtype of the included structure. In the above example, `astronaut` is a subtype of `person`; hence

```
(typep (make-astronaut) 'person)
```

is true, indicating that all operations on persons will work on astronauts.

The following is an advanced feature of the `:include` option. Sometimes, when one structure includes another, the default values or slot-options for the slots that came from the included structure are not what you want. The new structure can specify default values or slot-options for the included slots different from those the included structure specifies, by giving the `:include` option as:

`(:include` *name slot-description-1 slot-description-2 ...*`)`

Each *slot-description-j* must have a *slot-name* which is the same as that of some slot in the included structure. If *slot-description-j* has no *default-init*, then in the new structure the slot will have no initial value. Otherwise its initial value form will be replaced by the *default-init* in *slot-description-j*. A normally writable slot may be made read-only, and a normally visible slot may be made invisible in the defined structure. If a slot is invisible or read-only in the included structure, then it must also be so in the including structure. If a type is specified for a slot, it must be a the same as or a subtype of the type specified in the included structure. If it is a strict subtype, the implementation may or may not choose to error-check assignments.

For example, if we had wanted to define `astronaut` so that the default age for an astronaut is 45, then we could have said:

```
(defstruct (astronaut (:include person (age 45)))
   helmet-size
   (favorite-beverage 'tang))
```

`:make-array` If an array is used to represent the structure being defined (the `:type` (page 200) option is `:array` or `:array-leader`), this option allows you to control those aspects of the array used to implement the structure that are not otherwise constrained by `defstruct`. For example, if you are creating a structure of type `:array-leader`, you almost certainly want to specify the dimensions of the array to be created, and you may want to specify the type of the array.

The argument to the `:make-array` option should be a list of alternating keyword symbols to the function `make-array` (page 187) and forms whose values are the arguments to those keywords.

`defstruct` may need to specify some arguments to `make-array` for its own purposes. If these conflict with the specifications given to the `:make-array` keyword, an error is signalled.

> **Compatibility note:** This is more robust than the current Lisp Machine Lisp specification that `defstruct` quietly overrides what you specify.

Constructor macros for structures implemented as arrays all allow the keyword `:make-array` to be supplied. Attributes supplied therein override any `:make-array` option attributes supplied in the original `defstruct` form. If some attribute appears in neither the invocation of the constructor nor in the `:make-array` option to `defstruct`, then the constructor will chose appropriate defaults.

If a structure is of type `:array-leader`, you probably want to specify the dimensions of the array. The dimensions of an array are given to `:make-array` as a position argument rather than a keyword argument, so there is no way to specify them in the above syntax. To solve this problem, you may use the special keyword `:dimensions` or `:length` (they mean the same thing), with a value that is anything acceptable as `make-array`'s first argument.

`:print-function`

The argument to this option should be a function of four arguments which is to be used to print structures of this type. When a structure of this type is to be printed, the function is called on the structure to be printed, a stream to print to, an integer indicating the current depth (to be compared against `prinlevel` (page PRINLEVEL-VAR)), and a flag which is true for `prin1`-style printout and false for `princ`-style printout. This option can be used only with `:named` structures.

> **Compatibility note:** This is suggested merely to provide a simple way to set up the printing function in a central place and in an implementation-independent manner. In Lisp Machine Lisp this would presumably set up an invoke handler for the type. There needs to be a good way to interface to the grinder, too.

`:initial-offset`

This allows you to tell `defstruct` to skip over a certain number of slots before it starts allocating the slots described in the body. This option requires an argument (which must be a non-negative integer) which is the number of slots you want `defstruct` to skip. To make use of this option requires that you have some familiarity with how `defstruct` is implementing your structure; otherwise, you will be unable to make use of the slots that `defstruct` has left unused.

`:callable-accessors`

This option controls whether access functions are really functions, and therefore "callable", or whether thay are really macros. With an argument of `t`, or with no argument, or if the option is not provided, then the accessors are really functions. If the option is not provided, they are additionally declared `inline`, so that the compiler can integrate them into calling code for faster execution; explicitly providing the option suppresses this, so that they may be traced, for example. If the argument is `( )` then the accessors will really be macros, defined by `defmacro` (page DEFMACRO-FUN), just like the constructor and alterant macros.

> **Compatibility note:** So what about the above, which is not really compatible with Lisp Machine Lisp?

`:eval-when` Normally the macros defined by `defstruct` are defined at eval time, compile time, and load time. This option allows the user to control this behavior. The argument to the `:eval-when` option is just like the list that is the first subform of an `eval-when` (page EVAL-WHEN-FUN) special form. For example,

```
(:eval-when (:eval :compile))
```

will cause the macros to be defined only when the code is running interpreted or inside the compiler.

18.6. By-position Constructor Macros

If the `:constructor` (page 201) option is given as (`:constructor` *name arglist*), then instead of making a keyword driven constructor, `defstruct` defines a "function style" constructor, taking arguments whose meaning is determined by the argument's position rather than by a keyword. The *arglist* is used to describe what the arguments to the constructor will be. In the simplest case something like (`:constructor make-foo (a b c)`) defines `make-foo` to be a three-argument constructor macro whose arguments are used to initialize the slots named `a`, `b`, and `c`.

In addition, the keywords `&optional`, `&rest`, and `&aux` are recognized in the argument list. They work in the way you might expect, but there are a few fine points worthy of explanation.

For example:

```
(:constructor create-foo
        (a &optional b (c 'sea) &rest d &aux e (f 'eff)))
```

This defines `create-foo` to be a constructor of one or more arguments. The first argument is used to initialize the `a` slot. The second argument is used to initialize the `b` slot. If there isn't any second argument, then the default value given in the body of the `defstruct` (if given) is used instead. The third argument is used to initialize the `c` slot. If there isn't any third argument, then the symbol `sea` is used instead. Any arguments following the third argument are collected into a list and used to initialize the `d` slot. If there are three or fewer arguments, then `()` is placed in the `d` slot. The `e` slot *is not initialized*; its initial value is undefined. Finally, the `f` slot is initialized to contain the symbol `eff`.

The actions taken in the `b` and `e` cases were carefully chosen to allow the user to specify all possible behaviors. Note that the `&aux` "variables" can be used to completely override the default initializations given in the body.

With this definition, one can write

```
(create-foo 1 2)
```

instead of

```
(make-foo a 1 b 2)
```

and of course `create-foo` provides defaulting different from that of `make-foo`.

It is permissible to use the `:constructor` option more than once, so that you can define several different constructors, each with a different syntax.

Because this kind of constructor is a function, the arguments in a call to one will be evaluated in order. This is unlike a constructor macro, which may evaluate initialization forms in any order.

Compatibility note: In Lisp Machine LISP the evaluation can be in any order. This is a bad idea. It's not so hard to make it behave as a real function. Also, if you don't guarantee order, it's hard to let `&optional` and `&aux` initialization forms refer

to earlier variables properly; this is essential if we are not to confuse the user by using lambda-list syntax.

If you write the keyword `:make-array` in place of a variable name, then the corresponding argument will specify the `:make-array` option at construction time, just as for a constructor macro.

Chapter 19

EVAL

Chapter 20

Input/Output

20.1. Printed Representation of LISP Objects

LISP objects are not normally thought of as being text strings; they have very different properties from text strings as a consequence of their internal representation. However, to make it possible to get at and talk about LISP objects, LISP provides a representation of objects in the form of printed text; this is called the *printed representation*, which is used for input/output purposes and in the examples throughout this manual. Functions such as `print` (page 201) take a LISP object and send the characters of its printed representation to a stream. The collection of routines which does this is known as the (LISP) *printer*. The `read` function takes characters from a stream, interprets them as a printed representation of a LISP object, builds a corresponding object, and returns it; the collection of routines that does this is called the (LISP) *reader*.

Ideally, one could print a LISP object and then read the printed representation back in, and so obtain the same identical object. In practice this is difficult, and for some purposes not even desirable. Instead, reading a printed representation produces an object which is (with obscure technical exceptions) `equal` (page 40) to the originally printed object.

Most LISP objects have more than one possible printed representation. For example, the integer twenty-seven can be written in any of these ways:

```
27    27.    #o33    #x1B    #b11011    #.(* 3 3 3)
```

A list of two symbols A and B can be printed in many, many ways:

```
(A B)    (a b)    (  a  b )    (\A |B|)
   (|\A|
  B
)
```

The last example, which is spread over three lines, may be ugly, but it is legitimate. In general, wherever whitespace is permissible in a printed representation, any number of spaces, tab characters, and newlines may appear.

When `print` produces a printed representation, it must choose arbitrarily from among many possible printed representations. It attempts to choose one which is readable. There are a number of global variables which can be used to control the actions of `print`, and a number of different printing functions.

This section describes in detail what is the standard printed representation for any Lisp object, and also describes how `read` operates.

20.1.1. What the `read` Function Accepts

The purpose of the reader-LISP is to accept characters, interpret them as the printed representation of a LISP object, and construct and return such an object. The reader cannot accept everything that the printer produces; for example, the printed representations of compiled code objects and closures cannot be read in. However, the reader has many features which are not used by the output of the printer at all, such as comments, alternative representations, and convenient abbreviations for frequently-used unwieldy constructs. The reader is also parameterized in such a way that it can be used as a lexical analyzer for a more general user-written parser.

When the reader is invoked, it reads a character from the input stream and dispatches according to the attributes of that character. Every character which can appear in the input stream can have one of the following attributes:

- *Whitespace.*
- *Constituent.*
- *Macro character.*
- *Escape character.*

Supposing that the one character has been read; call it x. The reader then performs the following actions:

- If x is a *whitespace* character, then discard it and start over, reading another character.
- If x is a *macro character*, then execute the function associated with that character. The function may return a LISP object. If so, that object is returned by the reader; if not, the reader starts anew, reading a character from the input stream and dispatching. The function may of course read characters from the input stream; if it does, it will see those characters following the macro character.
- If x is an *escape character*, then read the next character and call it x instead, but pretend it is a *constituent*, and drop into the next case.
- If x is a *constituent*, then it begins an extended token, representing a symbol or a number. The reader reads more characters, accumulating them until a *whitespace* character or *macro character* is found. However, whenever an *escape character* is found during the accumulation, the character after that is treated as a pure *constituent* and also accumulated, no matter what its usual syntax is. Call the eventually found *whitespace* character or *macro character* y. All characters beginning with x up to but not including y form a single extended token, which is then interpreted as a number if possible, and otherwise as a symbol. The number or symbol is then returned by the reader.

Compatibility note: Note that characters of type *single* are not provided for. They can be viewed as simply a kind of macro

character. That is,

```
(setsyntax '$ 'single ())
  <=> (setsyntax '$ 'macro #'(lambda (ignore ignore) '$))
```

which is easy enough to do oneself. After all, one might prefer to see a character rather than a symbol.

<tab>	*whitespace*	<form>	*whitespace*	<return>	*whitespace*
<space>	*whitespace*	@	*constituent*	'	*macro character*
!	*constituent*	A	*constituent*	a	*constituent*
"	*macro character*	B	*constituent*	b	*constituent*
#	*macro character*	C	*constituent*	c	*constituent*
$	*constituent*	D	*constituent*	d	*constituent*
%	*constituent*	E	*constituent*	e	*constituent*
&	*constituent*	F	*constituent*	f	*constituent*
'	*macro character*	G	*constituent*	g	*constituent*
(	*macro character*	H	*constituent*	h	*constituent*
)	*macro character*	I	*constituent*	i	*constituent*
*	*constituent*	J	*constituent*	j	*constituent*
+	*constituent*	K	*constituent*	k	*constituent*
,	*macro character*	L	*constituent*	l	*constituent*
-	*constituent*	M	*constituent*	m	*constituent*
.	*constituent*	N	*constituent*	n	*constituent*
/	*constituent*	O	*constituent*	o	*constituent*
0	*constituent*	P	*constituent*	p	*constituent*
1	*constituent*	Q	*constituent*	q	*constituent*
2	*constituent*	R	*constituent*	r	*constituent*
3	*constituent*	S	*constituent*	s	*constituent*
4	*constituent*	T	*constituent*	t	*constituent*
5	*constituent*	U	*constituent*	u	*constituent*
6	*constituent*	V	*constituent*	v	*constituent*
7	*constituent*	W	*constituent*	w	*constituent*
8	*constituent*	X	*constituent*	x	*constituent*
9	*constituent*	Y	*constituent*	y	*constituent*
:	*constituent*	Z	*constituent*	z	*constituent*
;	*macro character*	[	*constituent*	{	*constituent*
<	*constituent*	\	*escape character*	|	*macro character*
=	*constituent*	]	*constituent*	}	*constituent*
>	*constituent*	^	*constituent*	~	*constituent*
?	*constituent*	←	*constituent*	<rubout>	*constituent*

Table 20-1: Standard Character Syntax Attributes

The characters of the standard character set initially have the attributes shown in Table 19-1.

If the reader encounters a macro character, then the function associated with that macro character is called, and may produce an object to be returned. This function may read following characters in the stream in whatever syntax it likes (it may even call `read` recursively) and returns the object represented by that syntax.

Macro characters may not be recognized, of course, when read as part of other special syntaxes (such as for strings).

The reader is therefore organized into two parts: the basic dispatch loop, which also distinguishes symbols and numbers, and the collection of macro characters. Any character can be reprogrammed as a macro character; this is a means by which the reader can be extended.

The general abilities of macro characters are discussed below in ???. First, however, some standard macro characters are described here:

(The left parenthesis character initiates reading of a pair or list. `Read` is called recursively to read successive objects, until a right parenthesis is found to be next in the input stream. A list of the objects read is returned. Thus

```
(a b c)
```

is read as a list of three objects (the symbols `a`, `b`, and `c`). The right parenthesis need not follow the printed representation of the last object immediately; whitespace characters may precede it. This can be useful for putting one object on each line and making it easy to add new objects:

```
(defun traffic-light (color)
  (caseq color
    (green)
    (red (stop))
    (amber (accelerate))          ; Insert more colors after this line.
    ))
```

It may be that *no* objects precede the right parenthesis, as in "`()`" or "`( )`"; this reads as a list of zero objects (the empty list).

If a token is read between objects which is just a dot "`.`", not preceded by an escape character, then exactly one more object must follow, and then the right parenthesis:

```
(a b c . d)
```

This means that the *cdr* of the last pair in the list is not `()`, but rather the object whose representation followed the dot. The above example might have been the result of evaluating

```
(cons 'a (cons 'b (cons 'c 'd))) => (a b c . d)
```

Similarly, we have

```
(cons 'znets 'wolq-zorbitan) => (znets . wolq-zorbitan)
```

It is permissible for the object following the dot to be a list:

```
(a b c d . (e f . (g)))   is the same as   (a b c d e f g)
```

but this is a non-standard form that `print` will never produce.

) The right-parenthesis character is part of various constructs (such as the syntax for lists) using the left-parenthesis character, and is invalid except when used in such a construct.

' The single-quote (accent acute) character provides an abbreviation to make it easier to put constants in programs. '*foo* reads the same as (`quote` *foo*): a list of the symbol `quote` and *foo*.

; Semicolon is used to write comments. The semicolon and everything up through the next newline are ignored. Thus a comment can be put at the end of any line without affecting the reader (except that semicolon, being a macro character and therefore a delimiter, will terminate a token, and so cannot be put in the middle of a number or symbol).

For example:

```
;;;; COMMENT-EXAMPLE and related nonsense.
;;; This function is useless except to demonstrate comments.
;;; Notice that there are several kinds of comments.

(defun comment-example (x y)    ;X is anything; Y is an a-list.
  (cond ((listp x) x)           ;If X is a list, use that.
        ;; X is now not a list.  There are two other cases.
        ((symbolp x)
         ;; Look up a symbol in the a-list.
         (cdr (assq x y)))      ;Remember, (cdr '()) is ().
        ;; Do this when all else fails:
        (t (cons x              ;Add x to a default list.
                 '((lisp t)     ;LISP is okay.
                   (fortran ()) ;FORTRAN is not.
                   (pl/i -500)  ;Note that you can put comments in
                   (ada .001)   ; "data" as well as in "programs".
                   ;; COBOL??
                   (teco -1.0e9))))))
```

This example illustrates a few conventions for comments in common use. Comments may begin with one to four semicolons.

- Single-semicolon comments are all aligned to the same column at the right; usually each comments about only the line it is on. Occasionally two or three contain a single sentence together; this is indicated by indenting all but the first by a space.
- Double-semicolon comments are aligned to the level of indentation of the code. A space follows the two semicolons. Usually each describes the state of the program at that point, or describes the section that follows.
- Triple-semicolon comments are aligned to the left margin. Usually they are not used within S-expressions, but precede them in large blocks.
- Quadruple-semicolon comments are interpreted as subheadings by some software such as the ATSIGN listing program.

" The double-quote character begins the printed representation of a string. Characters are read from the input stream and accumulated until another double-quote is encountered, except that if an escape character is seen, it is discarded, the next character is accumulated, and accumulation continues. When a matching double-quote is seen, all the accumulated characters up to but not including the matching double-quote are made into a string and returned.

| The vertical-bar character begins one printed representation of a symbol. Characters are read from the input stream and accumulated until another vertical-bar is encountered, except that if an escape character is seen, it is discarded, the next character is accumulated, and accumulation continues. When a matching vertical-bar is seen, all the accumulated characters up to but not including the matching

vertical-bar are made into a symbol and returned. In this syntax, no characters are ever converted to upper case; the name of the symbol is precisely those characters between the vertical bars (allowing for any escape characters).

' The backquote (accent grave) character makes it easier to write programs to construct complex data structures by using a template. As an example, writing

```
'(cond ((numberp ,x) ,@y) (t (print ,x) ,@y))
```

is roughly equivalent to writing

```
(list 'cond
      (cons (list 'numberp x) y)
      (list* 't (list 'print x) y))
```

See ??? for details.

, The comma character is part of the backquote syntax and is invalid if used other than inside the body of a backquote construction. See ???.

The sharp-sign character is a *dispatching* macro character. It reads an optional digit string and then one more character, and uses that character to select a function to run as a macro-character function. See the next section for predefined sharp-sign macro characters.

20.1.2. Sharp-Sign Abbreviations

The standard syntax includes forms introduced by a sharp sign ("#"). These take the general form of a sharp sign, a second character which identifies the syntax, and following arguments in some form. If the second character is a letter, then case is not important; #0 and #o are considered to be equivalent, for example. (To be precise, # *does* distinguish case, but for all standard syntaxes which use letters the same macro-character function is initially associated with the upper-case and lower-case versions of each letter.)

Certain sharp-sign forms allow an unsigned decimal number to appear between the sharp sign and the second character; some other forms even require it.

The currently-defined sharp-sign constructs are described below and summarized in Table 19-2; more are likely to be added in the future.

#\ #*x* reads in as a character object which represents the character *x*. Also, #*name* reads in as the character object whose name is *name*. This is the recommended way to include character constants in your code. Note that the backslash "\" allows this construct to be parsed easily by EMACS-like editors.

Upper-case and lower-case letters are distinguished after #\; "#\A" and "#\a" denote different character objects. Any character works after #\, even those that are normally special to `read`, such as parentheses. Non-printing characters may be used after #\, although for them names are generally preferred.

#*name* reads in as a character object whose name is *name* (actually, whose name is (`string-upcase` *name*)). The following names are standard across all implementations:

#<tab> signals error	#<form> signals error	#<return> signals error
#<space> signals error	#@ undefined	#' undefined
#! undefined	#A array	#a array
#" bit-string	#B binary rational	#b binary rational
## reference to label	#C complex number	#c complex number
#$ undefined	#D undefined	#d undefined
#% undefined	#E undefined	#e undefined
#& undefined	#F undefined	#f undefined
#' function abbreviation	#G undefined	#g undefined
#(general vector	#H undefined	#h undefined
#) signals error	#I undefined	#i undefined
#* undefined	#J undefined	#j undefined
#+ read-time conditional	#K undefined	#k undefined
#, load-time evaluation	#L undefined	#l undefined
#- read-time conditional	#M undefined	#m undefined
#. read-time evaluation	#N undefined	#n undefined
#/ undefined	#O octal rational	#o octal rational
#0 (infix argument)	#P undefined	#p undefined
#1 (infix argument)	#Q undefined	#q undefined
#2 (infix argument)	#R radix-*n* rational	#r radix-*n* rational
#3 (infix argument)	#S structure	#s structure
#4 (infix argument)	#T undefined	#t undefined
#5 (infix argument)	#U undefined	#u undefined
#6 (infix argument)	#V undefined	#v undefined
#7 (infix argument)	#W undefined	#w undefined
#8 (infix argument)	#X hexadecimal rational	#x hexadecimal rational
#9 (infix argument)	#Y undefined	#y undefined
#: undefined	#Z undefined	#z undefined
#; undefined	#[undefined	#{ undefined
#< signals error	#\ named character	#| undefined
#= labels LISP object	#] undefined	#} undefined
#> undefined	#^ undefined	#~ undefined
#? undefined	#← undefined	#<rubout> undefined

Table 20-2: Standard Sharp-Sign Macro Character Syntax

`return` The carriage return or newline character.

`space` The space or blank character.

The following names are semi-standard; if an implementation supports them, they should be used for the described characters and no others.

`rubout` The rubout or delete character.

`form` The formfeed or page-separator character.

`tab` The tabulate character.

`backspace` The backspace character.

`linefeed` The line feed character.

The *name* should have the syntax of a symbol.

When the LISP printer types out the name of a special character, it uses the same table as the `#\` reader; therefore any character name you see typed out is acceptable as input (in that implementation). Standard names are always preferred over non-standard names for printing.

The following convention is used in implementations which support non-zero bits attributes for character objects. If a name after `#\` is longer than one character and has a hyphen in it, then it may be split into the two parts preceding and following the first hyphen; the first part (actually, `string-upcase` of the first part) may then be interpreted as the name or initial of a bit, and the second part as the name of the character (which may in turn contain a hyphen and be subject to further splitting).

For example:

```
#\Control-Space                 #\Control-Meta-Tab
#\C-M-Return                    #\H-S-M-C-Rubout
```

If the character name consists of a single character, then that character is used. Another "\" may be necessary to quote the character.

```
#\Control-                      #\Control-Meta-\"
#\Control-\a                     #\Meta->
```

If an unsigned decimal integer appears between the "#" and "\", it is interpreted as a font number, to become the `char-font` (page 178) of the character object.

> **Compatibility note:** Formerly, Lisp Machine LISP and MACLISP used `#\` to mean only the `#\`*name* version of this syntax, using `#/` for the `#\`*x* version. Lisp Machine LISP has recently changed to allow `#/` to handle both syntaxes. The incompatibility is a result of the general exchange of the / and \ characters.
>
> Also, MACLISP and Lisp Machine LISP define `#\` and `#/` to be a syntax for *numbers*, integers which represent characters. Here they are a syntax for character objects. Code conforming to the "Character Standard for LISP" will not depend on this distinction; but non-conforming code (such as that which does arithmetic on bare character values) may not be compatible.

`#'` `#'`*foo* is an abbreviation for (`function` *foo*). *foo* may be the printed representation of any LISP object. This abbreviation can be remembered by analogy with the ' macro-character, since the `function` and `quote` special forms are similar in form.

`#(` A series of representations of objects enclosed by "`#(`" and "`)`" is read as a general vector of those objects. This is analogous to the notation for lists.

If an unsigned decimal integer appears between the "#" and "(", it specifies explicitly the length of the vector. In that case, it is an error if too many objects are specified before the closing "`)`", and if too few are specified the last one is used to fill all remaining elements of the vector.

For example:

```
#(a b c c c c)
#6(a b c c c c)
#6(a b c)
#6(a b c c)
```

all mean the same thing: a vector of length 6 with elements a, b, and four instances of c.

#" A series of binary digits (0 and 1) enclosed by "#"" and "" is read as a bit-string of those objects. This is analogous to the notation for strings.

If an unsigned decimal integer appears between the "#" and "", it specifies explicitly the length of the bit-string. In that case, it is an error if too many bits are specified before the closing "", and if too few are specified the last one is used to fill all remaining elements of the bit-string.

For example:

```
#"101000"
#6"101000"
#6"1010"
#6"10100"
#(@(mod 2) 1 0 1 0 0 0)
```

all mean the same thing.

#A This syntax denotes an array. A general array may be notated as "#*n*a" followed by the notation for a LISP object. The infix argument *n* indicates the rank (number of dimensions) of the array. The notated LISP object following "#*n*a" indicates the contents of the array in the following recursive manner. If the rank *n* is zero, then the object is the single element of the array. Otherwise, the object must be a sequence (a list or one-dimensional array). The length of that sequence is the first dimension of the array, and each element of the sequence must be an object describing the contents of an array of rank *n*-1 whose dimensions are the remaining dimensions of the rank-*n* array.

For example:

```
#0A foo                          ; A rank-0 array whose element is a symbol.
#2A((8 1 6) (3 5 7) (4 9 2))     ; A 3-by-3 array containing a magic square.
#1A#(2 3 5 7 11 13 17 19)        ; A one-dimensional array with eight primes.
#2A("ROT" "HEH" "ORE")           ; A 3-by-3 matrix of characters.
                                 ;   (The columns spell words also:
                                 ;   RHO, OER, and THE.)
#1A("ROT" "HEH" "ORE")           ; A 1-dimensional, length-3 array of strings.
#3A((() ()) (() ()) (() ()))     ; A 3-by-2-by-0 array; it has no elements.
#2A((() ()) (() ()) (() ()))     ; A 3-by-2 array, all of whose elements are ().
```

As another example, this notation is *not* legal:

```
#2a((1 2 3) (a b) (w x y z))
```

because the sublists are not all the same length, so it is unclear what the second dimension should be.

For convenience, if all of the sequences for rank-1 arrays in this notation are of the same specialized type, then the array will have that same underlying specialization if possible.

For example:

```
#2A("ROT" "HEH" "ORE")          ;This is of type (array string-char)
                                ;    if the implementation supports that type.
#1A#"00110101000101000101"      ;This is of type (array (mod 2))
                                ;    if the implementation supports that type.
```

Alternatively, one may specify the specialization explicitly. If the character immediately following the "A" is "@", then between the "@" and the representation of the array contents should appear the representation of the element type.

For example:

```
#2A@(mod 4) ((3 2) (0 1) (2 1)) ;A 3-by-2 array of type (array (mod 4)).
```

There is a problem with the #*n*A notation: there is no way to write a 0-by-3 array, for example. One might try writing `#2A()`, but this fails to specify that the second dimension should be 3. Another, less serious, problem with this notation is that it is annoying to notate a large array all of whose elements are the same.

There is a second notation for arrays that solves these problems. If no integer specifying the rank is written between the "#" and the "A", then there should follow the notation for a sequence of integers and then the notation for a sequence of objects. The length of the first sequence is the rank, and its elements are the dimensions; the second sequence specifies the values of the array elements in row-major order, with the understanding that if too few are given then the last element of the sequence is replicated, and if the sequence is empty the array contents are not initialized (it is as if no `:initial` option were specified to `make-array` (page 187)).

For example:

```
#A()(foo)                       ;Another notation for a zero-rank array containing foo.
#A(100 100 100)(0.0)            ;A cube, 100 on an edge, filled with 0.0.
#A(3 3)"ROTHEHORE"              ;The same matrix of characters as above.
#A(100)(2 3 5 0)                ;A 100-long array, filled with 2, 3, 5, and 97 zeros.
#A@(mod 7)(100)(2 3 5 0)        ;The same thing, but of specialized type.
#A(0 3)()                       ;A 0-by-3 array.
#A(0 4 0 5)()                   ;A 0-by-4-by-0-by-5 array.
```

#. `#.`*foo* is read as the object resulting from the evaluation of the LISP object represented by *foo*, which may be the printed representation of any LISP object. The evaluation is done during the `read` process, when the `#.` construct is encountered. This, therefore, performs a "read-time" evaluation of *foo*. By contrast, `#,` (see below) performs a "load-time" evaluation.

This allows you, for example, to include in your code complex list-structure constants which cannot be written with `quote`. Note that the reader does not put `quote` around the result of the evaluation. You must do this yourself if you want it, typically by using the ' macro-character. An example of a case where you do not want `quote` around it is when this object is an element of a constant list.

#, `#,`*foo* is read as the object resulting from the evaluation of the LISP object represented by *foo*, which may be the printed representation of any LISP object. The evaluation is done during the `read` process, *unless* unless the compiler is doing the reading, in which case it is arranged that *foo* will be evaluated when the file of compiled code is loaded. This, therefore, performs a "load-time" evaluation of *foo*. By contrast, `#.` (see above) performs a "read-time" evaluation. In a sense, `#,` is like specifying `(eval load)` to `eval-when` (page EVAL-WHEN-FUN), while `#.` is more like specifying `(eval compile)`. It makes no difference when loading interpreted code, but when code is to be compiled, `#.` specifies compile-time evaluation and `#,` specifies load-time evaluation.

#, allows you, for example, to include in your code complex list-structure constants which cannot be written with `quote`. Note that the reader does not put `quote` around the result of the evaluation. You must do this yourself if you want it, typically by using the ' macro-character. An example of a case where you do not want `quote` around it is when this object is an element of a constant list.

#B #b*rational* reads *rational* in binary (radix 2).

#O #o*rational* reads *rational* in octal (radix 8).

#X #x*rational* reads *rational* in hexadecimal (radix 16). The digits above 9 are the letters A through F (the lower-case letters a through f are also acceptable).

#R #*radix*r*rational* reads *rational* in radix *radix*. *radix* must consist of only digits, and it is read in decimal.

For example, `#3r102` is another way of writing `11`, and `#11R32` is another way of writing `35`. For radices larger than 10, letters of the alphabet are used in order for the digits after 9.

#s The syntax `#s(`*name slot1 value1 slot2 value2* `...)` denotes a structure. This is legal only if *name* is the name of a structure already defined by `defstruct` (page 197), and if the structure has a standard constructor macro, which it normally will. If it is assumed that the name of the constructor macro is `make-`*name* (which it normally is), then this syntax is equivalent to

```
(make-name slot1 'value1 slot2 'value2 ...)
```

That is, the constructor macro is called, with the specified slots having the specified values (note that one does not write quote-marks in the #s syntax). Whatever object the constructor macro returns is returned by the #s syntax.

#= The syntax *#n=object* reads as whatever LISP object has *object* as its printed representation. However, that object is labelled by *n*, a required unsigned decimal integer, for possible reference by the syntax *#n#* (below). The scope of the label is the S-expression being read by the outermost call to `read`. (??? Say this better.) Within this S-expression the same label may not appear twice.

??? Query: Should we require that a label occur textually before any references?

The syntax *#n#*, where *n* is a required unsigned decimal integer, serves as a reference to some object labelled by *#n=*; that is, *#n#* represents a pointer to the same identical (`eq`) object labelled by *#n=*. This permits notation of structures with shared or circular substructure. For example, a structure created in the variable y by this code:

```
(setq x (list 'p 'q))
(setq y (list (list 'a 'b) x 'foo x))
(rplacd (last x) (cdr x))
```

could be represented in this way:

```
((a b) . #1=(#2=(p q) foo #2# . #1#))
```

Without this notation, but with `prinlength` (page PRINLENGTH-VAR) set to 10, the structure would print in this way:

```
((a b) (p q) foo (p q) (p q) foo (p q) (p q) foo (p q) ...)
```

Compatibility note: In Lisp Machine LISP, the ## syntax is used for an obsolete version of character syntax which

is superseded in Lisp Machine LISP by `#/` and here by `#\`.

`#+` The `#+` syntax provides a read-time conditionalization facility. The general syntax is "*#+feature form*". If *feature* is "true", then this syntax represents a LISP object whose printed representation is *form*. If *feature* is "false", then this syntax is effectively whitespace; it is as if it did not appear.

The *feature* should be the printed representation of a symbol or list. If *feature* is a symbol, then it is true iff it is a member of the list which is the value of the global variable `features` (page FEATURES-VAR).

> Compatibility note: MACLISP uses the `status` special form for this purpose, and Lisp Machine LISP duplicates `status` essentially only for the sake of `(status features)`. The use of a variable allows one to bind the features list, for example when compiling.

Otherwise, *feature* should be a boolean expression composed of `and`, `or`, and `not` operators on (recursive) *feature* expressions.

For example, suppose that in implementation A the features `spice` and `perq` are true, and in implementation B the feature `lispm` is true. Then the expressions on the left below are read the same as those on the right in implementation A:

```
(cons #+spice "Spice" #+lispm "Lispm" x)   (cons "Spice" x)
(setq a '(1 2 #+perq 43 #+(not perq) 27))  (setq a '(1 2 43))
(let ((a 3) #+(or spice lispm) (b 3))      (let ((a 3) (b 3))
   (foo a))                                   (foo a))
```

In implementation B, however, they are read in this way:

```
(cons #+spice "Spice" #+lispm "Lispm" x)   (cons "Lispm" x)
(setq a '(1 2 #+perq 43 #+(not perq) 27))  (setq a '(1 2 27))
(let ((a 3) #+(or spice lispm) (b 3))      (let ((a 3) (b 3))
   (foo a))                                   (foo a))
```

The `#+` construction must be used judiciously if unreadable code is not to result. The user should make a careful choice between read-time conditionalization and run-time conditionalization. See the macros named `if-for-spice` (page IF-FOR-SPICE-FUN), `if-in-spice` (page IF-IN-SPICE-FUN), and so on.

`#-` *`#-feature form`* is equivalent to *`#+(not feature) form`*.

`#<` This is not legal reader syntax. It is used in the printed representation of objects which cannot be read back in. Attempting to read a `#<` will cause an error. (More precisely, it *is* legal syntax, but the macro-character function for it signals an error.)

`#<space>`, `#<tab>`, `#<return>`, `#<form>`
A `#` followed by a standard whitespace character is not legal reader syntax. This is so that abbreviated forms produced via `prinlevel` (page PRINLEVEL-VAR) cutoff will not read in again; this serves as a safeguard against losing information. (More precisely, it *is* legal syntax, but the macro-character function for it signals an error.)

`#)` This is not legal reader syntax. This is so that abbreviated forms produced via `prinlevel` (page PRINLEVEL-VAR) cutoff will not read in again; this serves as a safeguard against losing information. (More precisely, it *is* legal syntax, but the macro-character function for it signals an

error.)

20.1.3. The Readtable

Previous sections have described the standard syntax accepted by the `read` function. This section discusses the advanced topic of altering the standard syntax, either to provide extended syntax for LISP objects or to aid the writing of other parsers.

There is a data structure called the *readtable* which is used to control the reader. It contains information about the syntax of each character. Initially it is set up to give the standard LISP meanings to all the characters, but the user can change the meanings of characters to alter and customize the syntax of characters. It is also possible to have several readtables describing different syntaxes and to switch from one to another by binding the symbol `readtable`.

`readtable` [*Variable*]

The value of `readtable` is the current readtable. The initial value of this is a readtable set up for standard LISP syntax. You can bind this variable to temporarily change the readtable being used.

To program the reader for a different syntax, a set of functions are provided for manipulating readtables. Normally, you should begin with a copy of the standard COMMON LISP readtable and then customize the individual characters within that copy.

`copy-readtable &optional` *from-readtable to-readtable* [*Function*]

A copy is made of *from-readtable*, which defaults to the current readtable (the value of the global variable `readtable`). If *from-readtable* is `()`, then a copy of a standard COMMON LISP readtable is made; for example,

```
(setq readtable (copy-readtable ()))
```

will restore the input syntax to standard COMMON LISP syntax, even if the original readtable has been clobbered (assuming it is not so badly clobbered that you cannot type in the above expression!).

If *to-readtable* is unsupplied or `()`, a fresh copy is made. Otherwise *to-readtable* must be a readtable, which is clobbered with the copy.

`set-syntax-from-char` *to-char from-char* `&optional` *to-readtable from-readtable* [*Function*]

Makes the syntax of *to-char* in *to-readtable* be the same as the syntax of *from-char* in *from-readtable*. The *to-readtable* defaults to the current readtable (the value of the global variable `readtable` (page 193)), and *from-readtable* defaults to `()`, meaning to use the syntaxes from the standard LISP readtable.

If the definition of an ordinary character is copied, any special attributes it might have within a symbol or number are copied with it. The attributes in the standard readtable are shown in Table

<tab>	whitespace	{	alphabetic
<form>	whitespace	}	alphabetic
<return>	whitespace	'	macro character
<space>	whitespace	@	alphabetic
!	alphabetic	A, a	alphabetic, digit>10
"	macro character	B, b	alphabetic, digit>10
#	macro character	C, c	alphabetic, digit>10
$	alphabetic	D, d	alphabetic, digit>10, double-float exponent
%	alphabetic	E, e	alphabetic, digit>10, float exponent
&	alphabetic	F, f	alphabetic, digit>10, single-float exponent
'	macro character	G, g	alphabetic, digit>10
(	macro character	H, h	alphabetic, digit>10
)	macro character	I, i	alphabetic, digit>10
*	alphabetic	J, j	alphabetic, digit>10
+	alphabetic, plus sign	K, k	alphabetic, digit>10
,	macro character	L, l	alphabetic, digit>10, long-float exponent
-	alphabetic, minus sign	M, m	alphabetic, digit>10
.	alphabetic	N, n	alphabetic, digit>10
/	alphabetic, ratio marker	O, o	alphabetic, digit>10
0	digit	P, p	alphabetic, digit>10
1	digit	Q, q	alphabetic, digit>10
2	digit	R, r	alphabetic, digit>10
3	digit	S, s	alphabetic, digit>10, short-float exponent
4	digit	T, t	alphabetic, digit>10
5	digit	U, u	alphabetic, digit>10
6	digit	V, v	alphabetic, digit>10
7	digit	W, w	alphabetic, digit>10
8	digit	X, x	alphabetic, digit>10
9	digit	Y, y	alphabetic, digit>10
:	package marker	Z, z	alphabetic, digit>10
;	macro character	[	alphabetic
<	alphabetic	\	escape character
=	alphabetic	]	alphabetic
>	alphabetic	^	alphabetic
|	macro character	~	alphabetic
<rubout>	alphabetic		

underscore ?

Table 20-3: Standard Readtable Character Attributes

19-3. For example, if the definition of "S" is copied to "*", then "*" will be useable not only as an alphabetic character but as an exponent indicator in short-format floating-point number syntax.

> **Compatibility note:** No provision is made here for specifying the syntax attributes directly, as by keywords. It is more intuitive for the user simply to copy some standard character, and I believe that all the useful syntaxes are already provided in the standard readtable shown in Table 19-3.

It "works" to copy a macro definition from a character such as "|" to another character; the

standard definition for "|" looks for another character which is the same as the character which invoked it. It doesn't "work" to copy the definition of "(" to "{", for example; it does work, but lets one write lists in the form "{a b c)", not "{a b c}", because the definition always looks for a closing ")". See the function `read-delimited-list` (page 198), which is useful in this connection.

`set-macro-character` *char function* `&optional` *readtable* [*Function*]
`get-macro-character` *char* `&optional` *readtable* [*Function*]

`set-macro-character` causes *char* to be a macro character which when seen by `read` causes *function* to be called. `get-macro-character` returns the function associated with *char*, or `()` if *char* does not have macro-character syntax. In each case, *readtable* defaults to the current readtable.

function is called with two arguments, *stream* and *char*. The *stream* is the input stream, and *char* is the macro-character itself. In the simplest case, *function* may return a LISP object. This object is taken to be that whose printed representation was the macro character and any following characters read by the *function*. As an example, a plausible definition of the standard single-quote character is:

```
(defun single-quote-reader (stream ignore)
  (list 'quote (read stream)))
(set-macro-character #\' #'single-quote-reader)
```

The function reads an object following the single-quote and returns a list of the symbol `quote` and that object. The *char* argument is ignored.

The function may choose instead to return *zero* values (for example, by using `(values)` as the return expression). In this case the macro character and whatever it may have read contribute nothing to the object being read. As an example, here is a plausible definition for the standard semicolon (comment) character:

```
(defun semicolon-reader (stream ignore)
  (do () ((char= (inch stream) #\Return)))
  (values))
(set-macro-character #\; #'semicolon-reader)
```

As another example, here is a simplified definition of the `#+` syntax, which omits handling of `and`, `or` and `not`:

```
(defun sharp-plus-reader (stream ignore)
  (let ((feature (read stream))
        (object (read stream)))
    (if (memq feature features) object (values))))
(set-dispatch-macro-character #\# #\+ #'sharp-plus-reader)
```

If the feature is present, then `object` is returned, and otherwise nothing.

The *function* should not have any side-effects other than on the *stream* and *list-so-far*. Front ends (such as editors and rubout handlers) to the reader may cause *function* to be called repeatedly during the reading of a single expression in which the macro character only appears once, because of backtracking and restarting of the `read` operation.

`make-dispatch-macro-character` *char* `&optional` *readtable* [*Function*]

This causes the character *char* to be a dispatching macro character in *readtable* (which defaults to the current readtable). Initially every character in the dispatch table has a character-macro function which signals an error. Use `set-dispatch-macro-character` to define entries in the dispatch table.

`set-dispatch-macro-character` *disp-char sub-char function* `&optional` *readtable* [*Function*]
`get-dispatch-macro-character` *disp-char sub-char* `&optional` *readtable* [*Function*]

`set-dispatch-macro-character` causes *function* to be called when the *disp-char* followed by *sub-char* is read. The *readtable* defaults to the current readtable. The arguments and return values for *function* are the same as for normal macro characters, documented above under `set-macro-character` (page 223), except that *function* gets *sub-char* as its second argument, and also receives a third argument which is the non-negative integer whose decimal representation appeared between *disp-char* and *sub-char*, or ( ) if there was none. The *sub-char* may not be one of the ten decimal digits; they are always reserved for specifying an infix integer argument.

`get-dispatch-macro-character` returns the macro-character function for *sub-char* under *disp-char*.

As an example, suppose one would like #$*foo* to be read as if it were (`dollars` *foo*). One might say:

```
(defun sharp-dollar-reader (stream ignore ignore)
  (list 'dollars (read stream)))
(set-dispatch-macro-character #\# #\$ #'sharp-dollar-reader)
```

Compatibility note: This macro-character mechanism is different from those in MACLISP, INTERLISP, and Lisp Machine LISP. Recently LISP systems have implemented very general readers, even readers so programmable that they can parse arbitrary compiled BNF grammars. Unfortunately, these readers can be complicated to use, and have suffered from performance problems. This design is an attempt to make the reader as *simple* as possible to understand, use, and implement. Splicing macros have been eliminated; a recent informal poll indicates that no one uses them to produce other than zero or one value. The ability to access parts of the object preceding the macro character have been eliminated. The single-character-object feature has been eliminated, because it is seldom used and trivially obtainable by defining a macro.

The user is encouraged to turn off most macro characters, turn others into single-character-object macros, and then use `read` purely as a lexical analyzer on top of which to build a parser. It is unnecessary, however, to cater to more complex lexical analysis or parsing than that needed for COMMON LISP.

20.1.4. What the `print` Function Produces

20.2. Input Functions

20.2.1. Input from ASCII Streams

Many input functions take optional arguments called *input-stream* and *eof-option*. The *input-stream* argument is the stream from which to obtain input; if unsupplied or ( ) it defaults to the value of the special variable `standard-input` (page 216). One may also specify `t` as a stream, meaning the value of the special

variable `terminal-io` (page 217).

Rationale: Allowing the use of `t` provides some semblance of MACLISP compatibility.

The *eof-option* argument controls what happens if input is from a file (or any other input source that has a definite end) and the end of the file is reached. If no *eof-option* argument is supplied, an error will be signalled at end of file. If there is an *eof-option*, it is the value to be returned. Note that an *eof-option* of `()` means to return `()` if the end of the file is reached; it is *not* equivalent to supplying no *eof-option*. The *eof-option* argument is always evaluated; the resulting value is used, however, only when end of file is encountered.

Functions such as `read` (page 197) which read an "object" rather than a single character will always signal an error, regardless of *eof-option*, if the file ends in the middle of an object. For example, if a file does not contain enough right parentheses to balance the left parentheses in it, `read` will complain. If a file ends in a symbol or a number immediately followed by end-of-file, `read` will read the symbol or number successfully and when called again will see the end-of-file and obey *eof-option*. Similarly, the function `readline` (page 199) will successfully read the last line of a file even if that line is terminated by end-of-file rather than the newline character. If a file contains ignorable text at the end, such as blank lines and comments, `read` will not consider it to end in the middle of an object and will obey *eof-option*.

Compatibility note:

These end-of-file conventions are compatible with Lisp Machine LISP, but not completely compatible with Maclisp. Maclisp's deviations from this are generally considered to be bugs rather than features.

The MACLISP "feature" of letting *input-stream* and *eof-option* appear in either order is not supported.

Note that all of these functions will echo their input if used on an interactive stream. The functions that input more than one character at a time allow the input to be edited. The function `inchpeek` (page 199) echoes all of the characters that are skipped over (if any) if `inch` would have echoed them; the character not removed from the stream is not echoed either.

`read &optional` *input-stream eof-option* [*Function*]

`read` reads in the printed representation of a LISP object from *input-stream*, builds a corresponding LISP object, and returns the object. The details are explained above.

`read-preserve-delimiters` [*Variable*]

Certain printed representations given to `read`, notably those of symbols and numbers, require a delimiting character after them. (Lists do not, because the close parenthesis marks the end of the list.) Normally `read` will throw away the delimiting character if it is a white-space character, but will preserve it (using `untyi` (page 199)) if the character is syntactically meaningful, since it may be the start of the next expression.

The variable `read-preserve-delimiters` controls this throwing away of white-space characters. Its normal value is `()`, but if its value is not `()` then no delimiting characters will be thrown away by `read`, even if they are whitespace. This may be useful for certain macro characters or special input syntaxes.

As an example, consider this macro-character definition:

```
(defun slash-reader (stream ignore)
  (let ((read-preserve-delimiters t))
    (do ((path (list (read stream))
               (cons (progn (inch stream) (read stream))
                     path)))
        ((not (char= (inchpeek stream) #\/))
         (cons 'pathname (nreverse path))))))
(set-macro-character #\/ #'slash-reader)
```

Consider now calling `read` on this expression:

```
(zyedh /usr/games/zork /usr/games/boggle)
```

The "/" macro reads objects separated by more "/" characters; thus `/usr/games/zork` is intended to read as `(pathname usr games zork)`. The entire exmaple expression should therefore be read as

```
(zyedh (pathname usr games zork) (pathname usr games boggle))
```

However, if `read` were not instructed by the binding of the variable `read-preserve-delimiters` to preserve whitespace, then on reading the symbol `zork`, the following space would be discarded, and then the next call to `inchpeek` would see the following "/", and the loop would continue, producing this interpretation:

```
(zyedh (pathname usr games zork usr games boggle))
```

On the other hand, there are times when whitespace *should* be discarded. If one has a command interpreter which takes single-character commands, but occasionally reads a LISP object, then if the whitespace after a symbol were not discarded it might be interpreted as a command some time later after the symbol had been read.

`read-delimited-list` *char* `&optional` *input-stream* [*Function*]

This reads objects from *stream* until the next character after an object's representation (ignoring whitespace characters) is *char*. (The *char* should not have whitespace syntax in the current readtable.) A list of the objects read is returned.

This function is particularly useful for defining new macro-characters. Suppose one were to want "#{*a b c ... z*}" to read as a list of all pairs of the elements *a*, *b*, *c*, . . . , *z*; for example:

`#{p q z a}` read as `((p q) (p z) (p a) (q z) (q a) (z a))`

This can be done by specifying a macro-character definition for "#{" which does two things: read in all the items up to the "}", and construct the pairs. `read-delimited-list` performs the first task.

```
(defun sharp-leftbrace-reader (stream ignore ignore)
  (mapcon #'(lambda (x)
              (mapcar #'(lambda (y) (list x y)) (cdr x)))
          (read-delimited-list #\} stream)))
(set-dispatch-macro-character #\# #\{ #'sharp-leftbrace-reader)
```

Note that `read-delimited-list` does not take an *eof-option* argument. The reason for this is that it is always an error to hit end-of-file during the operation of `read-delimited-list`.

`readline &optional` *input-stream eof-option* [*Function*]

`readline` reads in a line of text, terminated by a carriage return. It returns the line as a character string, *without* the return character. This function is usually used to get a line of input from the user. A second returned value is a flag which is false if a carriage return terminated the line, or true if end-of-file terminated the (non-empty) line.

`inch &optional` *input-stream eof-option* [*Function*]
`tyi &optional` *input-stream eof-option* [*Function*]

`inch` inputs one character from *input-stream* and returns it as a character object. The character is echoed if *input-stream* is interactive.

`tyi` is similar to `inch`, but returns the character as an integer; it is as if `inch` were used, and `char-int` (page 179) applied to the result.

It is almost always preferable to use `inch` rather than `tyi`, if only for reasons of portability.

`uninch` *character* `&optional` *input-stream* [*Function*]
`untyi` *integer* `&optional` *input-stream* [*Function*]

`uninch` puts the *character* onto the front of *input-stream*. The *character* must be the same character that was most recently read from the *input-stream*. The *input-stream* "backs up" over this character; when a character is next read from *input-stream*, it will be the specified character, followed by the previous contents of *input-stream*. `uninch` returns `()`.

`untyi` is similar to `uninch`, but takes an integer rather than a character object. It is as if `uninch` were used after applying `int-char` (page 179) to the first argument. It is almost always preferable to use `uninch` rather than `untyi`, if only for reasons of portability.

One may only apply `uninch` or `untyi` to the character most recently read from input-*stream*; moreover, one may not invoke `uninch` or `untyi` twice consecutively without an intervening `inch` or `tyi` operation. The result is that one may back up only by one character, and one may not insert any characters into the input stream that were not already there.

> **Rationale:** This is not intended to be a general mechanism, but rather an efficient mechanism for allowing the Lisp reader and other parsers to perform one-character lookahead in the input stream. This protocol admits a wide variety of efficient implementations, such as simply decrementing a buffer pointer. To have to specify the character in the call to `uninch` is admittedly redundant, since there at any given time is only one character that may be legally specified. The redundancy is intentional, again to give the implementation latitude.

`inchpeek &optional` *peek-type input-stream eof-option* [*Function*]
`tyipeek &optional` *peek-type input-stream eof-option* [*Function*]

What `inchpeek` does depends on the *peek-type*, which defaults to `()`. With a *peek-type* of `()`, `inchpeek` returns the next character to be read from *input-stream*, without actually removing it from the input stream. The next time input is done from *input-stream* the character will still be there. It is as if one had called `inch` and then `uninch` in succession.

If *peek-type* is `t`, then `inchpeek` skips over whitespace characters, and then performs the peeking

operation on the next character. This is useful for finding the (possible) beginning of the next printed representation of a Lisp object. As above, the last character (the one that starts an object) is not removed from the input stream.

If *peek-type* is a character object, then `inchpeek` skips over input characters until a character which is `char=` (page 176) to that object is found; that character is left in the input stream.

Characters passed over by `inchpeek` are echoed if *input-stream* is interactive.

`tyipeek` is similar to `inchpeek`, but returns an integer rather than a character object; it is as if `inchpeek` were used, and `char-int` (page 179) applied to the result. (If, however, an *eof-option* is provided and returned, `char-int` is not applied!) `tyipeek` also requires an integer instead of a character as the *peek-type*.

It is almost always preferable to use `inchpeek` rather than `tyipeek`, if only for reasons of portability.

`listen &optional` *input-stream* [*Function*]

The predicate `listen` is true if there is a character immediately available from *input-stream*, and is false if not. This is particularly useful when the stream obtains characters from an interactive device such as a keyboard; a call to `inch` (page 227) would simply wait until a character was available, but `listen` can sense whether or not input is available and allow the program to decide whether or not to attempt input. On a non-interactive stream, the general rule is that `listen` is true except when at end-of-file.

`inch-no-hang &optional` *input-stream eof-option* [*Function*]
`tyi-no-hang &optional` *input-stream eof-option* [*Function*]

These functions are exactly like `inch` (page 227) and `tyi` (page 227), except that if it would be necessary to wait in order to get a character (as from a keyboard), `( )` is immediately returned without waiting. This allows one efficiently to check for input being available and get the input if it is. This is different from the `listen` (page 200) operation in two ways. First, these functions potentially actually read a character, while `listen` never inputs a character. Second, `listen` does not distinguish between end-of-file and no input being available, while these functions do make that distinction, returning *eof-option* at end-of-file (or signalling an error if no *eof-option* was given), but always returning `( )` if no input is available.

`clear-input &optional` *input-stream* [*Function*]

This clears any buffered input associated with *input-stream*. It is primarily useful for clearing type-ahead from keyboards when some kind of asynchronous error has occurred. If this operation doesn't make sense for the stream involved, when `clear-input` does nothing. `clear-input` returns `( )`.

`read-from-string` *string* `&optional` *eof-option* (*start* `0`) *end* [*Function*]

The characters of *string* are given successively to the LISP reader, and the LISP object built by the reader is returned. Macro characters and so on will all take effect.

The arguments *start* and *end* delimit a substring of *string* beginning at the character indexed by *start* and up to but not including the character indexed by *end*. By default *start* is `0` (the beginning of the string) and *end* is (`length` *string*). This is as for other string functions.

The *eof-option* is what to return if the end of the (sub)string is reached before the operation is completed, as with other reading functions.

`read-from-string` returns two values; the first is the object read and the second is the index of the first character in the string not read. If the entire string was read, this will be either the length of the string or one greater than the length of the string. The variable `read-preserve-delimiters` (page 225) affects this second value.

For example:

```
(read-from-string "(a b c)") => (a b c) and 7
```

20.2.2. Input from Binary Streams

20.2.3. Input Editing

20.3. Output Functions

20.3.1. Output to ASCII Streams

These functions all take an optional argument called *output-stream*, which is where to send the output. If unsupplied or (), *output-stream* defaults to the value of the variable `standard-output` (page 217). If it is `t`, the value of the variable `terminal-io` (page 217) is used.

`prin1` *object* `&optional` *output-stream* [*Function*]
`print` *object* `&optional` *output-stream* [*Function*]
`princ` *object* `&optional` *output-stream* [*Function*]

`prin1` outputs the printed representation of *object* to *output-stream*, using escape characters. As a rule, the output from `prin1` is suitable for input to the function `read` (page 225); see ???. `prin1` returns *object*.

`print` is just like `prin1` except that the printed representation of *object* is preceded by a <return> character and followed by a <space>. `print` returns *object*.

`princ` is just like `prin1` except that the output has no escape characters. A symbol is printed as simply the characters of its print-name; a string is printed without surrounding double-quotes; and there may be differences for other data types as well. The general rule is that output from `princ` is

intended to look good to people, while output from `prin1` is intended to be acceptable to the function `read` (page 225). `princ` returns *object*.

The output from these functions is affected by the values of the variables `base` (page BASE-VAR), `prinlevel` (page PRINLEVEL-VAR), and `prinlength` (page PRINLENGTH-VAR).

Compatibility note: In MACLISP, these three functions return `t`, not the argument *object*. There is some old code that depends on the value being non-`()`, such as in:

```
(and condition (print x) (print y) (print z))
```

which should have been written as

```
(cond (condition (print x) (print y) (print z)))
```

but someone was too lazy to do it that way (`when` didn't exist in those days). Ugh. COMMON LISP does not support this bad style.

`ouch` *character* `&optional` *output-stream* [*Function*]
`tyo` *integer* `&optional` *output-stream* [*Function*]

`ouch` outputs the *character* to *output-stream*.

`tyo` is similar, but takes an integer instead of a character; it is as if `int-char` were applied to the first argument and then `ouch` were called.

It is almost always preferable to use `ouch` rather than `tyo`, if only for reasons of portability.

Both functions return `t`.

`terpri` `&optional` *output-stream* [*Function*]
`fresh-line` `&optional` *output-stream* [*Function*]

`terpri` outputs a newline to *output-stream*; this may be simply a carriage-return character, a return-linefeed sequence, or whatever else is appropriate for the stream. `terpri` returns `()`.

`fresh-line` is similar to `terpri`, but outputs a newline only if the stream is not already at the start of a line. (If for some reason this cannot be determined, then a newline is output anyway.) This guarantees that the stream will be on a "fresh line" while consuming as little vertical distance as possible. `fresh-line` is a (side-effecting) predicate that is true if it output a newline, and otherwise false.

`force-output` `&optional` *output-stream* [*Function*]
`clear-output` `&optional` *output-stream* [*Function*]

Some streams may be implemented in an asynchronous or buffered manner. The function `force-output` attempts to ensure that all output sent to *output-stream* has reached its destination, and only then returns `()`.

The function `clear-output`, on the other hand, attempts to abort any outstanding output operation in progress, to allow as little output as possible to continue to the destination. This is useful, for example, to abort a lengthy output to the terminal when an asynchronous error occurs. `clear-output` returns `()`.

The function `format` (page 203) is very useful for producing nicely formatted text. It can do anything any of the above functions can do, and it makes it easy to produce good looking messages and such. `format` can generate a string or output to a stream.

The function `pprint` (page PPRINT-FUN) is useful for printing LISP objects "prettily" in an indented format. Also, `grindef` (page GRINDEF-FUN) is useful for formatting LISP programs.

20.3.2. Output to Binary Streams

20.4. Formatted Output

`format` *destination control-string* `&rest` *arguments* [*Function*]

`format` is used to produce formatted output. `format` outputs the characters of *control-string*, except that a tilde ("~") introduces a directive. The character after the tilde, possibly preceded by prefix parameters and modifiers, specifies what kind of formatting is desired. Most directives use one or more elements of *args* to create their output; the typical directive puts the next element of *args* into the output, formatted in some special way.

The output is sent to *destination*. If *destination* is `()`, a string is created which contains the output; this string is returned as the value of the call to `format`. In all other cases `format` returns `()`, performing output to *destination* as a side effect. If *destination* is a stream, the output is sent to it. If *destination* is `t`, the output is sent to the stream which is the value of the variable `standard-output` (page 217).

A `format` directive consists of a tilde ("~"), optional prefix parameters separated by commas, optional colon (":") and atsign ("@") modifiers, and a single character indicating what kind of directive this is. The alphabetic case of the directive character is ignored. The prefix parameters are generally decimal numbers. Examples of control strings:

```
"~S"        ;This is an S directive with no parameters or modifiers.
"~3,4:@s"   ;This is an S directive with two parameters, 3 and 4,
            ;    and both the colon and atsign flags.
"~,4S"      ;Here the first prefix parameter is omitted and takes
            ;    on its default value, while the second parameter is 4.
```

The `format` function includes some extremely complicated and specialized features. It is not necessary to understand all or even most of its features to use `format` effectively. The beginner should skip over anything in the following documentation that is not immediately useful or clear. The more sophisticated features are there for the convenience of programs with complicated formatting requirements.

Sometimes a prefix parameter is used to specify a character, for instance the padding character in a right- or left-justifying operation. In this case a single quote (" ' ") followed by the desired character may be used as a prefix parameter, so that you don't have to know the decimal numeric values of characters in the character

set. For example, you can use "~5,'0d" to print a decimal number in five columns with leading zeros, or "~5,'*d" to get leading asterisks.

In place of a prefix parameter to a directive, you can put the letter "V", which takes an argument from *arguments* as a parameter to the directive. Normally this should be an integer (but in general it doesn't really have to be). This feature allows variable column-widths and the like. Also, you can use the character "#" in place of a parameter; it represents the number of arguments remaining to be processed.

Here are some relatively simple examples to give you the general flavor of how `format` is used.

```
(format () "foo") => "foo"
(setq x 5)
(format () "The answer is ~D." x) => "The answer is 5."
(format () "The answer is ~3D." x) => "The answer is   5."
(format () "The answer is ~3,'0D." x) => "The answer is 005."
(format () "The answer is ~:D." (expt 47 x))
                                  => "The answer is 229,345,007."

(setq y "elephant")
(format () "Look at the ~A!" y) => "Look at the elephant!"
(format () "Type ~:C to ~A." (control #\D) "delete all your files")
      => "Type Control-D to delete all your files."

(setq n 3)
(format () "~D item~:P found." n) => "3 items found."
(format () "~R dog~:[s are~; is~] here." n (= n 1))
      => "three dogs are here."
(format () "~R dog~:*~[~1; is~:;s are~] here." n)
      => "three dogs are here."
(format () "Here ~[~1;is~:;are~] ~:*~R pupp~:@P." n)
      => "Here are three puppies."
```

The directives will now be described. The term *arg* in general refers to the next item of the set of *arguments* to be processed. The word or phrase at the beginning of each description is a mnemonic word for the directive.

`~A` *Ascii.* An *arg*, any LISP object, is printed without escape characters (as by `princ` (page 229)). In particular, if *arg* is a string, its characters will be output verbatim.

> **Compatibility note:** In COMMON LISP, the empty list always prints as `()`, so the colon modifier is useless here. In Lisp Machine LISP it specifies whether to print it as `()` or as `NIL`.

`~`*mincol*`A` inserts spaces on the right, if necessary, to make the width at least *mincol* columns. The `@` modifier causes the spaces to be inserted on the left rather than the right.

`~`*mincol*`,`*colinc*`,`*minpad*`,`*padchar*`A` is the full form of `~A`, which allows elaborate control of the padding. The string is padded on the right with at least *minpad* copies of *padchar*; padding characters are then inserted *colinc* characters at a time until the total width is at least *mincol*. The defaults are 0 for *mincol* and *minpad*, 1 for *colinc*, and the space character for *padchar*.

`~S` *S-expression.* This is just like `~A`, but *arg* is printed *with* escape characters (as by `prin1`

(page 229) rather than `princ`). The output is therefore suitable for input to `read` (page 225).

`~D` *Decimal.* An *arg*, a which should be an integer, is printed in decimal radix. `~D` will never put a decimal point after the number.

`~`*mincol*`D` uses a column width of *mincol*; spaces are inserted on the left if the number requires fewer than *mincol* columns for its digits and sign. If the number doesn't fit in *mincol* columns, additional columns are used as needed.

`~`*mincol*`,`*padchar*`D` uses *padchar* as the pad character instead of space.

If *arg* is not an integer, it is printed in `~A` format and decimal base.

The `@` modifier causes the number's sign to be printed always; the default is only to print it if the number is negative. The `:` modifier causes commas to be printed between groups of three digits; the third prefix parameter may be used to change the character used as the comma. Thus the most general form of `~D` is `~`*mincol*`,`*padchar*`,`*commachar*`D`.

`~B` *Binary.* This is just like `~D` but prints in binary radix (radix 2) instead of decimal. The full form is therefore `~`*mincol*`,`*padchar*`,`*commachar*`B`.

`~O` *Octal.* This is just like `~D` but prints in octal radix (radix 8) instead of decimal. The full form is therefore `~`*mincol*`,`*padchar*`,`*commachar*`O`.

`~X` *heXadecimal.* This is just like `~D` but prints in hexadecimal radix (radix 16) instead of decimal. The full form is therefore `~`*mincol*`,`*padchar*`,`*commachar*`X`.

`~R` *Radix.* `~`*n*`R` prints *arg* in radix *n*. The modifier flags and any remaining parameters are used as for the `~D` directive. Indeed, `~D` is the same as `~10R`. The full form here is therefore `~`*radix*`,`*mincol*`,`*padchar*`,`*commachar*`R`.

If no arguments are given to `~R`, then an entirely different interpretation is given. The argument should be an integer; suppose it is `4`.

- `~R` prints *arg* as a cardinal English number: `"four"`.
- `~:R` prints *arg* as an ordinal English number: `"fourth"`.
- `~@R` prints *arg* as a Roman numeral: `"IV"`.
- `~:@R` prints *arg* as an old Roman numeral: `"IIII"`.

`~P` *Plural.* If *arg* is not `eql` to `1`, a lower-case "s" is printed; if *arg* is `eql` to `1`, nothing is printed. (Notice that if *arg* is `1.0`, the "s" *is* printed.)

`~:P` does the same thing, after doing a `~:*` to back up one argument; that is, it prints a lower-case "s" if the *last* argument was not `1`. This is useful after printing a number using

~D.

~@P prints "y" if the argument is 1, or "ies" if it is not. ~:@P does the same thing, but backs up first.

```
(format () "~D tr~:@P/~D win~:P" 7 1) => "7 tries/1 win"
(format () "~D tr~:@P/~D win~:P" 1 0) => "1 try/0 wins"
(format () "~D tr~:@P/~D win~:P" 1 3) => "1 try/3 wins"
```

~F *Floating-point.*

??? Query: Is this really what we want?

arg is printed in floating point. ~*n*F rounds *arg* to a precision of *n* digits. The minimum value of *n* is 2, since a decimal point is always printed. If the magnitude of *arg* is too large or too small, it is printed in exponential notation. If *arg* is not a number, it is printed in ~A format. Note that the prefix parameter *n* is not *mincol*; it is the number of digits of precision desired. Examples:

```
(format () "~2F" 5)  =>  "5.0"
(format () "~4F" 5)  =>  "5.0"
(format () "~4F" 1.5) => "1.5"
(format () "~4F" 3.14159265)  =>  "3.142"
(format () "~3F" 1e10)  =>  "1.0e10"
```

~E *Exponential.*

??? Query: Is this the right thing Study PL/I, FORTRAN.

arg is printed in exponential notation. This is identical to ~F, including the use of a prefix parameter to specify the number of digits, except that the number is always printed with a trailing exponent, even if it is within a reasonable range.

~C *Character.* The next *arg* should be a character; it is printed according to the modifier flags.

~C prints the character in an implementation-dependent abbreviated format. This format should be culturally compatible with the host environment.

Implementation note: In Lisp Machine Lisp, the following format is used. If the character has any control bits set, and the output stream can represent the necessary Greek characters, then the control bits are output as alpha (α) for Control, beta (β) for Meta, lambda (λ) for Hyper, and pi (π) for Super. If the character itself is alpha, beta, lambda, pi, or equivalence-sign (≡), then it is preceded by an equivalence-sign to quote it. After all this, the base character itself is output.

Implementations which do not have Greek characters may well choose to represent control characters by initials and hyphens thus:

```
C-A          C-M-$          H-S-C-#
```

This has the advantage of staying within the standard character set.

~:C spells out the names of the control bits, and represents non-printing characters by their names: "Control-Meta-F", "Control-Return", "Space". This is a "pretty" format for printing characters.

~:@C prints what ~:C would, and then if the character requires unusual shift keys on the keyboard to type it, this fact is mentioned: "Control-∂ (Top-F)". This is the format

used for telling the user about a key he is expected to type, for instance in prompt messages. The precise output may depend not only on the implementation, but on the particular I/O devices in use.

~@C prints the character in a way that the LISP reader can understand, using "#\" syntax.

> **Rationale:** In some implementations the ~S directive would accomplish this also, but the ~C directive is compatible with LISP dialects which do not have a character data type.

~% Outputs a newline (see `terpri` (page 230)). ~*n*% outputs *n* newlines. No *arg* is used. Simply putting a newline in the control string would work, but ~% is often used because it makes the control string look nicer in the middle of a LISP program.

~& Unless the stream knows that it is already at the beginning of a line, this outputs a newline (see `fresh-line` (page 230)). ~*n*& does a `:fresh-line` operation and then outputs *n*−*1* newlines.

~| Outputs a page separator character, if possible. ~*n*| does this *n* times. With a : modifier, if the output stream supports the `clear-screen` (page CLEAR-SCREEN-FUN) operation this directive clears the screen; otherwise it outputs page separator character(s) as if no : modifier were present. | is vertical bar, not capital I.

~~ *Tilde.* Outputs a tilde. ~*n*~ outputs *n* tildes.

~<newline> Tilde immediately followed by a newline ignores the newline and any following non-newline whitespace. With a :, the newline is ignored but the whitespace is left in place. With an @, the newline is left in place but the whitespace is ignored. This directive is typically used when a format control string is too long to fit nicely into one line of the program:

```
(defun pet-rock-warning (rock friend amount)
  (unless (equalp rock friend)
          (format t "~&Warning!  Your pet rock ~A just ~
                     bit your friend ~A,~%  and ~
                     ~:[he~;she~] is suing you for $~D!"
                  rock friend (femalep friend) amount)))
(pet-rock-warning "Fred" "Susan" 500)  prints:
Warning:  Your pet rock Fred just bit your friend Susan,
  and she is suing you for $500!
```

~T *Tabulate.* Spaces over to a given column. ~*colnum*,*colinc*T will output sufficient spaces to move the cursor to column *colnum*. If the cursor is already past column *colnum*, it will output spaces to move it to column *colnum*+ *k***colinc*, for the smallest non-negative integer *k* possible. *colnum* and *colinc* default to 1.

~:T is like ~T, but *colnum* and *colinc* are in units of pixels, not characters; this makes sense only for streams which can set the cursor position in pixel units.

If for some reason the current column position cannot be determined or set, any ~T operation will simply output two spaces. When `format` is creating a string, ~T will work, assuming that the first character in the string is at the left margin (column 0).

~@T performs *relative* tabulation. ~*colrel*,*colinc*@T is equivalent to ~*curcol*+*colrel*,*colinc*@T where *curcol* is the current output column. If the current output column cannot be determined, however this outputs *colrel* spaces, not two spaces.

~:@T performs relative tabulation in units of pixels instead of columns.

~*

The next *arg* is ignored. ~*n** ignores the next *n* arguments.

~:* "ignores backwards"; that is, it backs up in the list of arguments so that the argument last processed will be processed again. ~*n*:* backs up *n* arguments.

When within a ~{ construct (see below), the ignoring (in either direction) is relative to the list of arguments being processed by the iteration.

This is a "relative goto"; for an "absolute goto", see ~G.

~*n*G

Goto. Goes to the *n*th *arg*, where 0 means the first one. Directives after a ~*n*G will take arguments in sequence beginning with the one gone to.

When within a ~{ construct, the "goto" is relative to the list of arguments being processed by the iteration.

This is an "absolute goto"; for a "relative goto", see ~*.

The format directives after this point are much more complicated than the foregoing; they constitute "control structures" which can perform conditional selection, iteration, justification, and non-local exits. Used with restraint, they can perform powerful tasks. Used with wild abandon, they can produce unreadable and unmaintainable spaghetti with goulash on top.

~[*str0*~;*str1*~;...~;*strn*~]

Conditional expression. This is a set of control strings, called *clauses*, one of which is chosen and used. The clauses are separated by ~; and the construct is terminated by ~]. For example,

```
"~[Siamese~;Manx~;Persian~;Tortoise-Shell~] Cat"
```

The *arg*th clause is selected, where the first clause is number 0. If a prefix parameter is given (as ~*n*[), then the parameter is used instead of an argument (this is useful only if the parameter is specified by "#"). If *arg* is out of range then no clause is selected. After the selected alternative has been processed, the control string continues after the ~].

~[*str0*~;*str1*~;...~;*strn*~:;*default*~] has a default case. If the *last* "~;" used to separate clauses is instead "~:;", then the last clause is an "else" clause, which is performed if no other clause is selected. For example:

```
"~[Siamese~;Manx~;Persian~;Tortoise-Shell~:;Alley~] Cat"
```

~[~*tag00*,*tag01*,...;*str0*~*tag10*,*tag11*,...;*str1*...~] allows the clauses to have explicit tags. The parameters to each ~; are numeric tags for the clause which follows it.

That clause is processed which has a tag matching the argument. If ~*a1*,*a2*,*b1*,*b2*,...:; (note the colon) is used, then the following clause is tagged not by single values but by ranges of values *a1* through *a2* (inclusive), *b1* through *b2*, etc. ~:; with no parameters may be used at the end to denote a default clause. For example:

```
"~[~'+,'-,'*,'/;operator ~'A,'Z,'a,'z:;letter ~
  ~'0,'9:;digit ~:;other ~]"
```

~:[*false*~;*true*~] selects the *false* control string if *arg* is (), and selects the *true* control string otherwise.

~@[*true*~] tests the argument. If it is not (), then the argument is not used up, but is the next one to be processed, and the one clause *true* is processed. If the *arg* (), then the argument is used up, and the clause is not processed. The clause therefore should normally use exactly one (non-()) argument. For example:

```
(setq prinlevel () prinlength 5)
(format () "~@[ PRINLEVEL=~D~]~@[ PRINLENGTH=~D~]"
           prinlevel prinlength)
   =>  " PRINLENGTH=5"
```

The combination of ~[and # is useful, for example, for dealing with English conventions for printing lists:

```
(setq foo "Items:~#[ none~; ~S~; ~S and ~
           ~S~:;~@{~#[~1; and~] ~S~^,~}~].")
(format () foo)
        =>  "Items: none."
(format () foo 'foo)
        =>  "Items: FOO."
(format () foo 'foo 'bar)
        =>  "Items: FOO and BAR."
(format () foo 'foo 'bar 'baz)
        =>  "Items: FOO, BAR, and BAZ."
(format () foo 'foo 'bar 'baz 'quux)
        =>  "Items: FOO, BAR, BAZ, and QUUX."
```

~; Separates clauses in ~[and ~< constructions. It is undefined elsewhere.

~] Terminates a ~[. It is undefined elsewhere.

~{*str*~} *Iteration.* This is an iteration construct. The argument should be a list, which is used as a set of arguments as if for a recursive call to `format`. The string *str* is used repeatedly as the control string. Each iteration can absorb as many elements of the list as it likes as arguments; if *str* uses up two arguments by itself, then two elements of the list will get used up each time around the loop. If before any iteration step the list is empty, then the iteration is terminated. Also, if a prefix parameter *n* is given, then there will be at most *n* repetitions of processing of *str*. Finally, the ~^ directive can be used to terminate the iteration prematurely.

Here are some simple examples:

```
(format () "The winners are:~{ ~S~}." '(fred harry jill))
     => "The winners are: FRED HARRY JILL."
(format () "Pairs:~{ <~S,~S>~}." '(a 1 b 2 c 3))
     => "Pairs: <A,1> <B,2> <C,3>."
```

~:{*str*~} is similar, but the argument should be a list of sublists. At each repetition step one sublist is used as the set of arguments for processing *str*; on the next repetition a new sublist is used, whether or not all of the last sublist had been processed. Example:

```
(format () "Pairs:~:{ <~S,~S>~}."
           '((a 1) (b 2) (c 3)))
     => "Pairs: <A,1> <B,2> <C,3>."
```

~@{*str*~} is similar to ~{*str*~}, but instead of using one argument which is a list, all the remaining arguments are used as the list of arguments for the iteration. Example:

```
(format () "Pairs:~@{ <~S,~S>~}."
           'a 1 'b 2 'c 3)
     => "Pairs: <A,1> <B,2> <C,3>."
```

~:@{*str*~} combines the features of ~:{*str*~} and ~@{*str*~}. All the remaining arguments are used, and each one must be a list. On each iteration the next argument is used as a list of arguments to *str*. Example:

```
(format () "Pairs:~:@{ <~S,~S>~}."
           '(a 1) '(b 2) '(c 3))
     => "Pairs: <A,1> <B,2> <C,3>."
```

Terminating the repetition construct with ~:} instead of ~} forces *str* to be processed at least once even if the initial list of arguments is null (however, it will not override an explicit prefix parameter of zero).

If *str* is empty, then an argument is used as *str*. It must be a string, and precedes any arguments processed by the iteration. As an example, the following are equivalent:

```
(funcall* #'format stream string args)
(format stream "~1{~:}" string args)
```

This will use `string` as a formatting string. The `~1{` says it will be processed at most once, and the `~:}` says it will be processed at least once. Therefore it is processed exactly once, using `args` as the arguments.

As another (rather sophisticated) example, the `format` function itself uses `format-error` (a routine internal to the `format` package) to signal error messages, which in turn uses `ferror`, which uses `format` recursively. Now `format-error` takes a string and arguments, just like `format`, but also prints the control string to `format` (which at this point is available in the variable `ctl-string`) and a little arrow showing where in the processing of the control string the error occurred. The variable `ctl-index` points one character after the place of the error.

```
(defun format-error (string &rest args)
  (ferror () "~1{~:}~%~VT↓~%~3X\"~A\"~%"
          string args (+ ctl-index 3) ctl-string))
```

This first processes the given string and arguments using ~1{~:}, then goes to a new line, tabs a variable amount for printing the down-arrow, and prints the control string between double-quotes. The effect is something like this:

```
(format t "The item is a ~[Foo~;Bar~;Loser~]." 'quux)
>>ERROR: The argument to the FORMAT "~[" command
         must be a number.
                    ↓
   "The item is a ~[Foo~;Bar~;Loser~]."
...
```

~} Terminates a ~{. It is undefined elsewhere.

~*mincol*,*colinc*,*minpad*,*padchar*<*str*~>

Justification. This justifies the text produced by processing *str* within a field at least *mincol* columns wide. *str* may be divided up into segments with ~;, in which case the spacing is evenly divided between the text segments.

With no modifiers, the leftmost text segment is left justified in the field, and the rightmost text segment right justified; if there is only one, as a special case, it is right justified. The : modifier causes spacing to be introduced before the first text segment; the @ modifier causes spacing to be added after the last. The *minpad* parameter (default 0) is the minimum number of padding characters to be output between each segment. The padding character is specified by *padchar*, which defaults to the space character. If the total width needed to satisfy these constraints is greater than *mincol*, then the width used is *mincol*+*k***colinc* for the smallest possible non-negative integer value *k*; *colinc* defaults to 1, and *mincol* defaults to 0.

Examples:

```
(format () "~10<foo~;bar~>")          =>  "foo    bar"
(format () "~10:<foo~;bar~>")         =>  "  foo  bar"
(format () "~10:@<foo~;bar~>")        =>  "  foo bar "
(format () "~10<foobar~>")            =>  "    foobar"
(format () "~10:<foobar~>")           =>  "    foobar"
(format () "~10@<foobar~>")           =>  "foobar    "
(format () "~10:@<foobar~>")          =>  "  foobar  "
(format () "$~10,,,'*<~3F~>" 2.59023) =>  "$******2.59"
```

Note that *str* may include `format` directives. All the clauses in *str* are processed in order; it is the resulting pieces of text that are justified. The last example illustrates how the ~< directive can be combined with the ~F directive to provide more advanced control over the formatting of numbers.

??? Query: Unfortunatly, the ~F command as defined above isn't really flexible enough?

The ~^ directive may be used to terminate processing of the clauses prematurely, in which case only the completely processed clauses are justified.

If the first clause of a ~< is terminated with ~:; instead of ~;, then it is used in a special way. All of the clauses are processed (subject to ~^, of course), but the first one is not used

in performing the spacing and padding. When the padded result has been determined, then if it will fit on the current line of output, it is output, and the text for the first clause is discarded. If, however, the padded text will not fit on the current line, then the text segment for the first clause is output before the padded text. The first clause ought to contain a newline (such as a ~% directive). The first clause is always processed, and so any arguments it refers to will be used; the decision is whether to use the resulting segment of text, not whether to process the first clause. If the ~:; has a prefix parameter *n*, then the padded text must fit on the current line with *n* character positions to spare to avoid outputting the first clause's text. For example, the control string

```
"~%;; ~{~<~%;; ~1:; ~S~>~^,~}.~%"
```

can be used to print a list of items separated by commas, without breaking items over line boundaries, and beginning each line with ";; ". The prefix parameter 1 in ~1:; accounts for the width of the comma which will follow the justified item if it is not the last element in the list, or the period if it is. If ~:; has a second prefix parameter, then it is used as the width of the line, thus overriding the natural line width of the output stream. To make the preceding example use a line width of 50, one would write

```
"~%;; ~{~<~%;; ~1,50:; ~S~>~^,~}.~%"
```

If the second argument is not specified, then `format` uses the line width of the output stream. If this cannot be determined (for example, when producing a string result), then `format` uses 72 as the line length.

~> Terminates a ~<. It is undefined elsewhere.

~↑ *Up and out.* This is an escape construct. If there are no more arguments remaining to be processed, then the immediately enclosing ~{ or ~< construct is terminated. If there is no such enclosing construct, then the entire formatting operation is terminated. In the ~< case, the formatting *is* performed, but no more segments are processed before doing the justification. The ~^ should appear only at the *beginning* of a ~< clause, because it aborts the entire clause it appears in (as well as all following clauses). ~^ may appear anywhere in a ~{ construct.

```
(setq donestr "Done.~^  ~D warning~:P.~^  ~D error~:P.")
(format () donestr) => "Done."
(format () donestr 3) => "Done.  3 warnings."
(format () donestr 1 5) => "Done.  1 warning.  5 errors."
```

If a prefix parameter is given, then termination occurs if the parameter is zero. (Hence ~^ is equivalent to ~#^.) If two parameters are given, termination occurs if they are equal. If three are given, termination occurs if the second is between the other two in ascending order. Of course, this is useless if all the prefix parameters are constants; at least one of them should be a # or a V parameter.

If ~^ is used within a ~:{ construct, then it merely terminates the current iteration step (because in the standard case it tests for remaining arguments of the current step only); the next iteration step commences immediately. To terminate the entire iteration process, use ~:^.

Here are some examples of the use of ~^ within a ~< construct.

```
(format () "~15<~S~;~^~S~;~^~S~>" 'foo)
        =>  "              FOO"
(format () "~15<~S~;~^~S~;~^~S~>" 'foo 'bar)
        =>  "FOO           BAR"
(format () "~15<~S~;~^~S~;~^~S~>" 'foo 'bar 'baz)
        =>  "FOO    BAR    BAZ"
```

Compatibility note: The ~Q directive and user-defined directives have been omitted here, as well as control lists (as opposed to strings), which are rumored to be changing in meaning.

20.5. Querying the User

The following functions provide a convenient and consistent interface for asking questions of the user. Questions are printed and the answers are read using the stream `query-io`, which normally is synonymous with `terminal-io` but can be rebound to another stream for special applications.

We describe first two simple functions for asking yes-or-no questions, and then the general function `fquery` on which all querying is built.

`y-or-n-p &optional` *message stream* [*Function*]

This predicate is for asking the user a question whose answer is either "yes" or "no". It types out *message* (if supplied and not ( )), reads a one-character answer, echoes it as "`Yes.`" or "`No.`", and is true if the answer was "yes" or false if the answer was "no". The characters which mean "yes" are `Y`, `y`, `T`, `t`, and space. The characters which mean "no" are `N`, `n`, and rubout. If any other character (? in particular) is typed, the function will demand a "Y or N" answer.

Implementation note: Some implementations may choose to allow other characters to be valid answers, such as "hand-up" and "hand-down" in Lisp Machine LISP.

If the *message* argument is supplied, it will be printed on a fresh line (see `fresh-line` (page 230)). Otherwise it is assumed that a message has already been printed. If you want a question mark and/or a space at the end of the message, you must put it there yourself; `y-or-n-p` will not add it. *stream* defaults to the value of the global variable `query-io` (page 217).

As an example, consider this call:

```
(y-or-n-p "Cannot establish connection.  Retry?  ")
Cannot establish connection.  Retry?
                                        ↑ Input cursor is now here.
```

The second line above was printed by `y-or-n-p`. The third line does not show, but is shown here to indicate where the cursor is when input is expected. If the user type `Y`, then the interaction looks like this:

```
(y-or-n-p "Cannot establish connection.  Retry?  ")
Cannot establish.connection.  Retry?  Yes.
```

Now the cursor is just after "`Yes.`".

`y-or-n-p` should only be used for questions which the user knows are coming. If the user is unlikely to anticipate the question, or if the consequences of the answer might be grave and irreparable, then `y-or-n-p` should not be used, because the user might type ahead a `T`, `Y`, `N`, space, or rubout, and thereby accidentally answer the question. For such questions as "Shall I delete all of your files?", it is better to use `yes-or-no-p` (below).

`yes-or-no-p &optional` *message stream* [*Function*]

This predicate, like `y-or-n-p`, is for asking the user a question whose answer is either "Yes" or "No". It types out *message* (if supplied and not ( )), beeps, and reads in a line from the keyboard. If the line is the string "Yes", it is true. If the line is "No", it is false. (Case is ignored, as are leading and trailing spaces and tabs.) If the input line is anything else, `yes-or-no-p` beeps and demands a "yes" or "no" answer. If a ? is typed at any point, a message will be printed demanding a "yes" or "no" answer.

If the *message* argument is supplied, it will be printed on a fresh line (see `fresh-line` (page 230)). Otherwise the caller is assumed to have printed the message already. If you want a question mark and/or a space at the end of the message, you must put it there yourself; `yes-or-no-p` will not add it. *stream* defaults to the value of the global variable `query-io` (page 217).

To allow the user to answer a yes-or-no question with a single character, use `y-or-n-p`. `yes-or-no-p` should be used for unanticipated or momentous questions; this is why it beeps and why it requires several keystrokes to answer it.

The preceding two functions allow the asking of simple yes-or-no questions. More complicated questions can be asked using `fquery`, described below. `fquery` is quite general and complicated. It is best to write some interface function for each particular kind of question, using `fquery` in the definition. In this way the complicated arguments to `fquery` need be written in only a few places.

`fquery` *options format-string* `&rest` *format-args* [*Function*]

This asks a question, printed by executing

```
(format query-io format-string format-args...)
```

and returns the answer. `fquery` takes care of checking for valid answers, reprinting the question when the user clears the screen, giving help, and so forth.

options is a list of alternating keywords and values, used to select among a variety of features. Most callers will have a constant list to pass as *options* (rather than consing up a different list each time).

`:type` The expected form of the answer. The types currently defined are:

- `:inch` A single character, as read by `inch` (page 227). This the default.
- `:tyi` This is similar to `inch`; the answer is a single character, but the result is an integer, as if read by `tyi` (page 227).

`:readline` A string, typed as a line terminated by a carriage return, as read by `readline` (page 227).

`:choices` Defines the allowed answers. The allowed forms of choices are complicated and explained below. The default is the same set of choices as for `y-or-n-p` (page 241), if `:type` is `:inch` or `:tyi`, or the same as for `yes-or-no-p`, if `:type` is `:readline`. Note that the `:type` and `:choices` options should be consistent with each other.

Compatibility note: In Lisp Machine Lisp, `:choices` always defaults to `y-or-n-p` choices, even if `:type` is `:readline`. This is clearly bogus.

`:list-choices`
If true, the allowed choices are listed (in parentheses) after the question. The default is true; supplying false causes the choices not to be listed unless the user tries to give an answer which is not one of the allowed choices.

`:help-function`
Specifies a function to be called if the user types "?". The default help-function simply lists the available choices. Specifying ( ) disables the special treatment of "?". Specifying a function of three arguments (the stream, the value of the `:choices` option, and the type-function) allows smarter help processing. The type-function is a function selected by the `:type` option; it does `inch`, `tyi`, or `readline`, but with additional processing. Often it can be ignored by the help-function.

`:fresh-line` If true (the default), `query-io` is advanced to a fresh line before asking the question. If false, the question is printed wherever the cursor was left by previous typeout.

`:beep` If true, `fquery` beeps to attract the user's attention to the question. The default is false, which means not to beep unless the user tries to give an answer which is not one of the allowed choices.

`:clear-input`
If true, `fquery` throws away type-ahead before reading the user's response to the question. Use this for unexpected questions. The default is false, which means not to throw away typeahead unless the user tries to give an answer which is not one of the allowed choices. In that case, type-ahead is discarded since the user probably wasn't expecting the question.

The argument to the `:choices` option is a list each of whose elements is a *choice*. The cdr of a choice is a list of the user inputs which correspond to that choice. These should be characters if the `:type` is `:inch`, integers corresponding to characters for `:tyi`, or strings for `:readline`. The car of a choice is either an atom which `fquery` should return if the user answers with that choice (in which case nothing is echoed), or a list whose first element is such an atom and whose second element is the string to be echoed when the user selects the choice.

Compatibility note: In Lisp Machine Lisp the choice-value is specified to be a symbol. To allow ( ) to be returned, or even integers, atoms (non-lists) are specified here.

In most cases a `:type` of `:readline` would use the first format, since the user's input has already been echoed, and `:inch` or `:tyi` would use the second format, since the input has not been

echoed and furthermore is a single character, which would not be mnemonic to see on the display.

As an example, here is a definition of the function `y-or-n-p` in terms of `fquery`:

```
(defun y-or-n-p (&optional message (stream query-io))
  (let ((query-io stream))
    (fquery '(:fresh-line ()
              :list-choices ()
              :choices
                  (((t "Yes.") #\y #\t #\Space)
                   ((() "No.") #\n #\Rubout)))
            (if message "~&~a" "~*")
            message)))
```

As another example, here is a definition of `yes-or-no-p`:

```
(defun y-or-n-p (&optional message (stream query-io))
  (let ((query-io stream))
    (fquery '(:fresh-line ()
              :list-choices ()
              :beep t
              :type :readline
              :choices ((t "Yes") (() "No")))
            (if message "~&~a" "~*")
            message)))
```

As a third example, this function allows more complex choices. One may type `P`, `Q`, `R`, or `D`, in which respective cases the symbol `proceed`, `quit`, `retry`, or `debug` is returned. Space or rubout may be typed instead of `P` or `Q`, respectively.

```
(defun ask-i/o-error-action &optional message (stream query-io)
  (let ((query-io stream))
    (fquery '(:fresh-line ()
              :list-choices t
              :choices
                  (((proceed "Proceed") #\p #\Space)
                   ((quit "Quit") #\q #\Rubout)
                   ((retry "Retry") #\r)
                   ((debug "Debug") #\d)))
            (if message "~&~a" "~*")
            message)))
```

20.6. Streams

Streams first? in chapter?

20.6.1. Standard Streams

There are several global variables whose values are streams used by many functions in the LISP system. These variables and their uses are listed here. By convention, variables which are expected to hold a stream capable of input have names ending with "`-input`", and similarly "`-output`" for output streams. Those expected to hold a bidirectional stream have names ending with "`-io`".

`standard-input` [*Variable*]

In the normal LISP top-level loop, input is read from `standard-input` (that is, whatever stream is the value of the global variable `standard-input`). Many input functions, including `read` (page 225) and `inch` (page 227), take a stream argument which defaults to `standard-input`.

`standard-output` [*Variable*]

In the normal LISP top-level loop, output is sent to `standard-output` (that is, whatever stream is the value of the global variable `standard-output`). Many output functions, including `print` (page 229) and `ouch` (page 230), take a stream argument which defaults to `standard-output`.

`error-output` [*Variable*]

The value of `error-output` is a stream to which error messages should be sent. Normally this is the same as `standard-output`, but `standard-output` might be bound to a file and `error-output` left going to the terminal or a separate file of error messages.

`query-io` [*Variable*]

The value of `query-io` is a stream which should be used when asking questions of the user. The question should be output to this stream, and the answer read from it. When the normal input to a program may be coming from a file, questions such as "Do you really want to delete all of the files in your directory??" should be sent directly to the user, and the answer should come from the user, not from the data file. `query-io` is used by such functions as `yes-or-no-p` (page 242).

`terminal-io` [*Variable*]

The value of `terminal-io` is ordinarily the stream which connects to the user's console.

`trace-output` [*Variable*]

The value of `trace-output` is the stream on which the `trace` function prints its output.

`standard-input`, `standard-output`, `error-output`, `trace-output`, and `query-io` are initially bound to synonym streams which pass all operations on to the stream which is the value of `terminal-io`. (See `make-synonym-stream` (page 218).) Thus any operations performed on those streams will go to the terminal.

No user program should ever change the value of `terminal-io`. A program which wants (for example) to divert output to a file should do so by binding the value of `standard-output`; that way error messages sent to `error-output` can still get to the user by going through `terminal-io`, which is usually what is desired.

20.6.2. Creating New Streams

Perhaps the most important constructs for creating new streams are those which open files; see `with-open-file` (page 222) and `open` (page 224).

`make-synonym-stream` *symbol* [*Function*]

`make-synonym-stream` creates and returns a "synonym stream". Any operations on the new stream will be performed on the stream which is then the value of the dynamic variable named by the *symbol*. If the value of the variable should change or be bound, then the synonym stream will operate on the new stream.

> ??? Query: In Lisp Machine Lisp this is called `make-syn-stream`. The documentor found it necessary to explain that "syn" meant "synonym"; it certainly isn't obvious. The abbreviation "syn" could be mistaken for any number of other things, such as "synchronous" or "syntactic" or "synthetic" ... Here this confusion is eliminated.

`make-broadcast-stream &rest` *streams* [*Function*]

Returns a stream which only works in the output direction. Any output sent to this stream will be sent to all of the streams given. The set of operations which may be performed on the new stream is the intersection of those for the given streams. The results returned by a stream operation are the values returned by the last stream in *streams*; the results of performing the operation on all preceding streams are discarded.

`make-concatenated-stream &rest` *streams* [*Function*]

Returns a stream which only works in the input direction. Input is taken from the first of the *streams* until it reaches end-of-file; then that stream is discarded, and input is taken from the next of the *streams*, and so on. If no arguments are given, the result is a stream with no content; any input attempt will result in end-of-file.

`make-io-stream` *input-stream output-stream* [*Function*]

Returns a bidirectional stream which gets its input from *input-stream* and sends its output to *output-stream*.

`make-echo-stream` *input-stream output-stream* [*Function*]

Returns a bidirectional stream which gets its input from *input-stream* and sends its output to *output-stream*. In addition, all input taken from *input-stream* is echoed to *output-stream*.

`make-string-input-stream` *string* [*Function*]

Returns an input stream which will supply the characters of *string* in order and then signal end-of-file.

`make-string-output-stream &optional` *line-length* [*Function*]

Returns an output stream which will accumulate all output given it for the benefit of the function `get-output-stream-string`.

`get-output-stream-string` *string-output-stream* [*Function*]

Given a stream produced by `make-string-output-stream`, this returns a string containing all the characters output to the stream so far. The stream is then reset; thus each call to `get-output-stream-string` gets only the characters since the last such call (or the creation of the stream, if no such previous call has been made).

20.6.3. Operations on Streams

`streamp object` [*Function*]

`streamp` is true if its argument is a stream, and otherwise is false.

```
(streamp x) <=> (typep x 'stream)
```

`input-stream-p` *stream* [*Function*]

This predicate is true if its argument (a stream) can handle input operations, and otherwise is false.

`output-stream-p` *stream* [*Function*]

This predicate is true if its argument (a stream) can handle output operations, and otherwise is false.

`close` *stream* `&optional` *abort-flag* [*Function*]

The stream is closed. No further input/output operations may be performed on it. However, certain inquiry operations may still be performed, and it is permissible to close an already-closed stream.

If *abort-flag* is not ( ) (it defaults to ( )), it indicates an abnormal termination of the use of the stream. An attempt is made to clean up any side effects of having created the stream in the first place. For example, if the stream performs output to a file, the file is deleted and any previously existing file is not superseded.

`charpos`, `linenum`, and so on?

20.7. File System Interface

20.7.1. File Names

There are two representations of the name of a file as LISP objects: namestrings and namelists. A *namestring* is a string (or symbol, whose print-name is used) which is the name of the file in an implementation-dependent and file-system-dependent syntax. This representation is intended for use by people. A *namelist* is a list in a special format which is less readable, but more portable and suitable for manipulation by programs.

The model of the file system embodied by namelists is a three-level hierarchy of *host*, *directory*, and *file*. This model is crude, but adapts itself reasonably well to most contemporary operating systems. Generally speaking, a host is thought of as some single computer, a directory as a single lowest-level group of related files within that host, and a file as the smallest named unit of data within the file system. Each of the three levels may be specified by a compound name consisting of a non-empty list of components, each of which may be a string, symbol, or integer: a string is used as a component name; a symbol is used as a special keyword; and an integer is used for its decimal representation, with optional minus sign and no leading zeros. Symbols which have special meaning are:

`*` This indicates an *unspecified* component.

`:newest` As a version number, this indicates the most recent version (for input), or one greater than the most recent version (for output creation).

`:oldest` As a version number, this indicates the least recent version.

The general and canonical form of a namelist is:

(*host-name* . *directory-name*) . *file-name*)

The *host-name* may be unambiguously elided, in which case all its components are taken to be * (unspecified); similarly, the list (*host-name* . *directory-name*) may be unambiguously elided, in which case all components of both *host-name* and *directory-name* are taken to be *.

As an example, suppose that host CMUC is a TOPS-20 system. Then a file name on that system might be:

```
PS:<SLISP.MANUAL>LISTS.MSS.43
```

and the corresponding namelist might be:

```
(((CMUC) PS SLISP MANUAL) LISTS MSS 43)
```

Similarly, this partially specified file name:

```
<SLISP.MANUAL>LISTS.*
```

might be rendered as a namelist in this way:

```
(((*) * SLISP MANUAL) LISTS * *)
```

Most functions which accept namelists also accept namestrings, and will, in effect, first parse the namestring to produce a namelist. If the namestring is malformed and therefore cannot be parsed, an error will be signaled.

`namelist` *filespec* [*Function*]

The *filespec* argument may be a namelist, a namestring, or a stream which is or was open to a file. The name represented by *filespec* is returned as a namelist in canonical form.

If *filespec* is a stream, the name returned represents the name used to *open* the file, which may not be the *actual* name of the file (see `truename` (page 221)).

`namestring` *filespec* [*Function*]
`file-namestring` *filespec* [*Function*]
`directory-namestring` *filespec* [*Function*]
`host-namestring` *filespec* [*Function*]
`enough-namestring` *filespec defaults* [*Function*]

The *filespec* argument may be a namelist, a namestring, or a stream which is or was open to a file. The name represented by *filespec* is returned as a namelist in canonical form.

If *filespec* is a stream, the name returned represents the name used to *open* the file, which may not be the *actual* name of the file (see `truename` (page 221)).

`namestring` returns the full form of the *filespec* as a string. `file-namestring` returns a string representing just the *file-name* portion of the *filespec*; the result of `directory-namestring` represents just the *directory-name* portion; and `host-namestring` returns a string for just the *host-name* portion. Note that the full namestring cannot necessarily be constructed simply by concatenating the three shorter strings in some order.

`enough-namestring` takes another argument, *defaults*, which also should be a namelist, namestring, or file-stream. It returns an abbreviated namestring which is just sufficient to identify the file named by *filespec* when considered relative to the *defaults*. That is,

```
(mergef (enough-namestring filespec defaults) defaults)
  <=> (namelist filespec)
```

`parse-namestring` *string* `&optional` *break-characters start end* [*Function*]

This is the primitive namestring parser. It takes a string argument, and parses a file name within it in the range delimited by *start* and *end* (which are integer indices into *string*, defaulting to the beginning and end of the string). Parsing is terminated upon reaching the end of the specified substring or upon reaching a character in *break-characters*, which may be a string or a list of characters; this defaults to an empty set of characters.

Two values are returned by `parse-namestring`. If the parsing is successful, then the first value is a namelist for the parsed file name, and otherwise the first value is `( )`. The second value is an integer, the index into *string* one beyond the last character processed. This will be equal to *end* if processing was terminated by hitting the end of the substring; it will be the index of a break character if such was the reason for termination; it will be the index of an illegal character if that was what caused processing to (unsuccessfully) terminate.

Parsing an empty string always succeeds, producing a namelist with all components unspecified.

`truename` *file-stream* [*Function*]

`truename` returns a namelist for the *actual* name of the file which is or was associated with the stream *file-stream*. This may differ from the name used to open the file because of such file-system features as links, searching for oldest or newest versions, etc.

`mergef` *filespec1 filespec2* [*Function*]

Each argument must be a namelist, namestring, or stream which is or was open to a file. A namelist is constructed and returned whose components are taken from *filespec1*, except that components unspecified ("*") in *filespec1* are taken from *filespec2*. Components not specified by either argument remain unspecified in the result.

`file-name-type` *filespec* [*Function*]
`file-name-version` *filespec* [*Function*]

The argument must be a namelist, namestring, or stream which is or was open to a file. `file-name-type` returns the type part of the *filespec*; `file-name-version` returns the version part of the *filespec*.

`merge-file-name-type` *type filespec* [*Function*]
`merge-file-name-version` *version filespec* [*Function*]

A namelist is returned equivalent to *filespec* except that the first argument specifies the type or version part; a first argument of * forces the appropriate part to be unspecified. The first argument must be a symbol, string, or integer; the *filespec* argument must be a namelist, namestring, or stream which is or was open to a file.

20.7.2. Opening and Closing Files

When a file is *opened*, a stream object is constructed which is the file system's ambassador to the LISP environment; operations on the stream are reflected by operations on the file in the file system. The act of *closing* the file (actually, the stream) ends the association; the transaction with the file system is terminated, and input/output may no longer be performed on the stream. The stream function `close` (page 247) may be used to close a file; the functions described below may be used to open them.

`with-open-file` *bindspec* {*form*}* [*Special form*]

`(with-open-file (stream filename options) . body)` evaluates the forms of *body* (an implicit `progn`) with the variable *stream* bound to a stream which reads or writes the file named by the value of *filename*. The *options* should evaluate to a keyword or list of keywords.

When control leaves the body, either normally or abnormally (such as by use of `throw` (page 77)), the file is closed. If a new output file is being written, and control leaves abnormally, the file is aborted and it is, so far as possible, as if it had never been opened. Because `with-open-file` always closes the file, even when an error exit is taken, it is preferred over `open` for most applications.

filename is the name of the file to be opened; it can be a namelist or namestring. If an error occurs (such as "File Not Found"), the user is asked to supply an alternate pathname, unless this is overridden by *options*. At that point the user can quit or enter the error handler if the error was not due to a misspelled pathname after all.

options is either a single keyword or a (possibly empty) list of options, where an option is either a keyword or a list of a keyword and arguments to that keyword. (If a keyword with an argument is to be used, then *options* must be a list of options and not a single option.)

> Compatibility note: Lisp Machine LISP uses a format where the argument to a keyword simply follows the keyword in the list. This is not compatible with other keyword formats, for example that of `defstruct`. It only makes a difference here in the case of `:byte-size`. It seems worthwhile to minimize the number of keyword formats in COMMON LISP.

Valid keywords are:

`:in` or `:input` or `:read`
: Open file for input. This is the default.

`:out` or `:output` or `:write` or `:print`
: Open file for output; a new file is to be created.

`:append`
: Open an existing file for output, arranging that output to the resulting stream should be appended to the previous contents of the file.

> Compatibility note: Not all file systems can support this operation. An implementation may choose to simulate it by copying the old file into a new one and then continuing to write the new one.
>
> Compatibility note: The Lisp Machine LISP implementation appears not to support this, but MACLISP does in the `open` function.

`:read-alter`
: Open a file in read-alter mode; the result is a stream which can perform both input and output on a random-access file.

> Compatibility note: Not all file systems can support this operation.

`:character` or `:ascii`
: The unit of transaction is a character; the file is a text file. This is the default.

`:binary` or `:fixnum`
: The unit of transaction is a small unsigned integer. The `:byte-size` option may be used to specify the number of binary bits in the transaction unit. This precise way in which this interacts with the file system is implementation-dependent.

`:byte-size`
: This keyword takes an argument, an integer specifying the number of bits per transaction unit; this is used in conjunction with the `:binary` option. If the `:binary` keyword is specified but the `:byte-size` keyword is not, then an implementation-dependent "natural" byte size is used.

`:echo`
: This keyword requires an argument, an output stream, and is valid only when opening a stream for input. The result stream will echo everything read from it onto the output stream.

`:probe`
: This keyword specifies that the file is not being opened to do I/O, but only to find out information about it. A stream is returned, but it cannot handle I/O

transactions; it is as if the stream were immediately closed after opening it. `:probe` implies `:noerror` (see below).

??? Query: In Lisp Machine LISP, `:probe` also implies `:fixnum`. Why??

`:noerror` If the file cannot be opened, then instead of returning a stream, a string containing the error message is returned. If `:noerror` is not specified, then an error is signalled using the error message, and the user is asked to supply a different filename.

`open` *filename* `&optional` *options* [*Function*]

Returns a stream which is connected to the file specified by *filename*. The *options* argument is as for `with-open-file` (page 250). If an error occurs, such as "File Not Found", the user is asked to supply an alternate pathname, unless the `:noerror` (page 223) option is used, in which case the error message is returned as a string.

When the caller is finished with the stream, it should close the file by using the `close` (page 247) function. The `with-open-file` (page 250) special form does this automatically, and so is preferred for most purposes. `open` should be used only when the control structure of the program necessitates opening and closing of a file in some way more complex than provided by `with-open-file`. It is suggested that any program which uses `open` directly should use the special form `unwind-protect` (page 76) to close the file if an abnormal exit occurs.

Implementation note: While `with-open-file` tries to automatically close the stream on exit from the construct, for robustness it is helpful if the garbage collector can detect discarded streams and automatically close them.

20.7.3. Renaming, Deleting, and Other Operations

`renamef` *file new-name* `&optional` *error-p* [*Function*]

file can be a filename or a stream which is open to a file. The specified file is renamed to *new-name* (a filename). If *error-p* is true (the default), then if a file-system error occurs it will be signalled as a LISP error. If *error-p* is false and an error occurs, the error message will be returned as a string. If no error occurs, `renamef` returns `()`.

`deletef` *file* `&optional` *error-p* [*Function*]

file can be a filename or a stream which is open to a file. The specified file is deleted. If *error-p* is true (the default), then if a file-system error occurs it will be signalled as a LISP error. If *error-p* is false and an error occurs, the error message will be returned as a string. If no error occurs, `deletef` returns `()`.

`probef` *filename* [*Function*]

This pseudo-predicate is false if there is no file named *filename*, and otherwise returns a filename which is the true name of the file (which may be different from *filename* because of file links, version numbers, or other artifacts of the file system).

`faslp` *file* `&optional` *implementation* [*Function*]

file can be a filename or a stream which is open to a file. This predicate is true if the file is a fasload (compiled) file in *implementation* format, and otherwise is false. The argument *implementation* defaults to the implementation in which the call is executed.

`file-creation-date` *file* [*Function*]

file can be a filename or a stream which is open to a file. This returns the creation date of the file as an integer in universal time format, or `()` if this cannot be determined.

`file-author` *file* [*Function*]

file can be a filename or a stream which is open to a file. This returns the name of the author of the file as a string, or `()` if this cannot be determined.

`filepos` *file-stream* `&optional` *position* [*Function*]

`filepos` returns or sets the current position within a random-access file.

(`filepos` *file-stream*) returns a non-negative integer indicating the current position within the *file-stream*, or `()` if this cannot be determined. Normally, the position is zero when the stream is first created. For a `:character` (page 251) stream, the position is in units of characters; for a `:binary` (page 251) file, the position is in bytes.

(`filepos` *file-stream position*) sets the position within *file-stream* to be *position*. The *position* may be an integer, or `()` for the beginning of the stream, or `t` for the end of the stream. If the integer is too large, an error occurs (the `lengthf` (page 225) function returns the length beyond which `filepos` may not access). With two arguments, `filepos` is a (side-effecting) predicate that is true if it actually performed the operation, or false if it could not.

`lengthf` *file-stream* [*Function*]

file-stream must be a stream which is open to a file. The length of the file is returned as a non-negative integer, or `()` if the length cannot be determined. For a `:character` (page 251) stream, the position is in units of characters; for a `:binary` (page 251) file, the position is in bytes.

20.7.4. Loading Files

To *load* a file is to read through the file, evaluating each form in it. Programs are typically stored in files; the expressions in the file are mostly special forms such as `defun` (page 29), `defmacro` (page DEFMACRO-FUN), and `defvar` (page 30) which define the functions and variables of the program.

Loading a compiled ("fasload") file is similar, except that the file does not contain text, but rather predigested expressions created by the compiler which can be loaded more quickly.

`load` *filename* `&optional` *package nonexistent-ok do-not-set-default* [*Function*]

This function loads the file named by *filename* into the Lisp environment. If the file is a fasload file, it calls `fasload`; otherwise it calls `readfile`. The argument *package* can be used to specify the package into which to load the file; it can be either a package or the name of a package as a string or a symbol. If *package* is not specified, `load` prints a message saying what package the file is being loaded into. If *nonexistent-ok* is specified and not `()`, `load` just returns `()` if the file cannot be opened. If the file is successfully loaded, `load` always returns a non-`()` value.

`load` maintains a default filename, used to default missing components of the *filename* argument; thus `(load)` will load the same file previously loaded. Normally `load` updates the filename defaults from *filename*, but if *dont-set-default* is specified and not `()` this is suppressed.

If *filename*, after defaulting, is still missing components in such a way that it does not specify either a fasload or LISP source file, then `load` first tries to open a fasload file, and failing that tries to load a LISP source file, in each case trying to load the most recent version.

`readfile` `&optional` *filename package no-msg-p* [*Function*]

`readfile` is the version of `load` (page 226) for text files. It reads and evaluates each expression in the file, discarding the results. As with `load`, *package* can specify what package to read the file into. Unless *no-msg-p* is specified and not `()`, a message is printed indicating what file is being read into what package. The defaulting of *filename* is the same as with `load`.

`fasload` *filename* `&optional` *package no-msg-p* [*Function*]

`fasload` is the version of `load` for fasload (compiled) files. It defines functions and performs other actions as directed by the specifications inserted in the file by the compiler; the result is roughly the same as performing `readfile` on the original source file, but faster, and with functions being in compiled form. As with `load`, *package* can specify what package to read the file into. Unless *no-msg-p* is specified and not `()`, a message is printed indicating what file is being loaded into what package. The defaulting of *filename* is the same as with `load`.

??? Query: There are several problems with the above specifications, which are essentially as in Lisp Machine LISP.

- The arguments for the three functions are not compatible; there is not even a subset relationship.
- The file name defaulting has been criticized as being "very M.I.T."; not all cultures prefer to maintain default file names in this way.
- There ought to be an option to print the results of each evaluation (and in the case of `fasload`, the name of each function as it is loaded). Another flavor of this option is to print a one-character blip every so often to signal progress. This is useful for debugging, for example to determine where in a load file an error is occurring.

These problems should be fixed.

20.7.5. Accessing Directories

Chapter 21

Errors

COMMON LISP handles errors through a system of *conditions*. One may establish *handlers* which gain control which conditions occur, and *signal* a condition when an error actually occurs. When the system or a user function detects an error it signals an appropriately named condition and some handler established for that condition will deal with it.

The condition mechanism is completely general and could be used for purposes other than "error" handling. There are some functions supplied in COMMON LISP which make use of the condition mechanism to handle errors in a convenient way.

21.1. Signalling Conditions

Condition handlers are associated with conditions (see next section). Every condition is essentially a name, which is a symbol or `()`. When an unusual situation occurs, such as an error, a condition is signalled. The system (essentially) searches up the stack of nested function invocations looking for a handler established to handle that condition. The handler is a function which gets called to deal with the condition.

`signal` *condition-name* `&rest` *args* [*Function*]

This searches through all currently established condition handlers, perhaps twice, starting with the most recent. If it finds one which was established to handle `()` or *condition-name*, then it calls that handler with a first argument of *condition-name* and with *args* as the rest of the arguments. If the first value returned by the handler is `()`, `signal` will continue searching for another handler; otherwise it will return the first two values returned by the handler. If *condition-name* is not `t`, and if no handler was willing to handle the condition, then a second pass of the established condition handlers is made, searching for any handler established to handle `t`. If one is found that is used in the same manner as in the first pass search. If there is still no willing handler found then `signal` returns `()`.

Thus a handler set up to handle condition `()` will handle *all* conditions which are not handled by a more recently established handler. This is intended to make it easy to set up a debugger which intercepts all errors and handles them itself. Note that such a handler doesn't have to actually handle all conditions; it will be

offered the chance to do so but can return ( ) to refuse any condition which it doesn't wish to handle.

Conditions established to handle condition `t` will handle *any* condition for which a more specific willing handler can't be found. This makes it easy to set up, at any time, a handler which which will be given a chance to handle all conditions that no one else wants.

21.2. Establishing Handlers

Condition handlers are established through the `condition-bind` or `condition-setq` special forms. These have behaviors somewhat analagous to `let` and `setq`. They make use of the ordinary variable binding mechanism, so that if a `condition-bind` is thrown through the handlers get disestablished. It also means that in multiple stack group implementations of COMMON LISP the handlers are established only in the current stack group.

`condition-bind` *bindings* {*form*}* [*Special form*]

This is used to establish handlers for conditions then perform the *body* in that established handler environment.

For example:

For example:

```
(condition-bind ((cond1 hand1)
                 (cond2 hand2)
                 ...
                 (condm handm))
  form1
  form2
  ...
  formn)
```

Each *condj* is either the name of a condition or a list of names of conditions. Each *handj* is a form which is evaluated to produce a handler function. No guarantee is made on the order of evaluation of these forms, but the conditions are established in sequential order, so that *cond1* will be looked at first. The expressions *formj* are then evaluated in order; the values of all but the last are discarded (that is, the body of the `condition-bind` form is an implicit `progn`). The value of the `condition-bind` form is the value of *formn* (if the body is empty, ( ) is the value). The established conditions become disestablished when the `condition-bind` form is exited.

As an example consider:

For example:

```
(condition-bind ((:wrong-type-argument 'some-wta-handler)
                 ((silliness-1 silliness-2) silliness-handler))
  (format msgfiles '"Yodle-eh-eh-ho!")
  (+ 23 ()))
```

This sets up the function `some-wta-handler` to handle the `:wrong-type-argument` condition. The value of the symbol `silliness-handler` is set up to handle both the

`silliness-1` and `silliness-2` conditions. With these handlers set up, it outputs a message and then causes a `:worng-type-argument` error by trying to add 23 to `()`, which is not a number. The condition handler `some-wta-handler` will be given a chance to handle the error.

`condition-setq` {*spec*}* [*Special form*]

The `condition-setq` form is used to establish condition handlers as a side effect of some operation -- for instance loading a file which contains condition handlers and a `condition-setq` form to establish them.

It takes the form:

For example:

```
(condition-setq cond1 hand1
                cond2 hand2
                ...
                condn handn)
```

Each *condj* is either the name of a condition or a list of names of conditions. Each *handj* is a form which is evaluated to produce a handler function. No guarantee is made on the order of evaluation of these forms, but the conditions are established in sequential order, so that *cond1* will be looked at first.

The conditions established by `condition-setq` remain established until execution is unwound (either normally or by being thrown) past the most recent `condition-bind`. Multiple uses of `condition-setq` cause the most recently established handler to be tried first when a condition is signalled. For example, consider:

For example:

```
(condition-setq :wrong-type-argument 'default-wta-handler)
(+ 23 ())
(condition-setq :worng-type-argument 'hairy-wta-handler)
(+ 105 ())
```

When the first `:wrong-type-argument` error is signalled (because of the attempt to add 23 to `()`) the function `default-wta-handler` will be given first chance at handling the error. When the second error is signalled (because of the attempt to add 105 to `()`) the function `hairy-wta-handler` will be given first chance. If it declines (by returning `()` as its first result) then `default-wta-handler` will be given a chance.

21.3. Error Handlers

When `signal` (page 257) invokes a condition handler it passes it the *condition-name* along with whatever other arguments were handed to `signal`. Condition handlers set up to handle errors can safely assume certain things about those arguments for all errors signalled by the system or signalled by user code via the functions `ferror` (page 233) and `cerror` (page 233).

An error handler can expect to be invoked as

For example:

```
(funcall* error-handler
          condition-name
          control-string
          proceedable-flag
          restartable-flag
          function
          params)
```

where *params* may vary in length. Handlers for particular condition names may expect certain parameters to always be included in the *params* list. The parameters supplied by the system for certain standard conditions are given in ???section-ref "standard condition names"???. The program siganalling the condition is free to pass any extra parameters. All error handlers should therefore be written with `&rest` arguments.

The *condition-name* is the name of the condition signalled.

control-string should be a string which when given to `format` (page 231) as a control string, along with *params* as additional arguments, produces some reasonable explanation of the error. It is up to the handling function whether it makes use of that control string.

The third and fourth arguments are flags. If the *proceedable-flag* is non-`()` then the error is said to be *proceedable*. If the *restartable-flag* is non-`()` then the error is said to be *restartable*. The values of these flags may be used by the signallers and handlers to pass more information than a single bit. It is up to the user how these are used. For instance, a set of signallers and handlers may pass information concerning the values expected from the handler when an error is proceeded.

function is the name of the function which initiated the signalling of the error, or `()` if the signaller can't determine it.

An error handler can do some processing and then make one of four respones to the error (assuming the error was signalled with `ferror` (page 233) or `cerror` (page 233)). It can return `()` to decline handling the error, it can *proceed*, it can *restart* or it can *throw*.

Throwing simply consists of using the function `throw` (page 77) to some tag outside the scope of the error.

Proceeding and *Restarting* are achieved by returning from the error handler with multiple values. The first value should be one of the following:

`:return` This means to *proceed* the error. If the error was signalled by `cerror` and the error was proceedable then the second value returned with `:return` is returned as the value of `cerror`. If the error was not proceedable (always the case for errors signalled by `ferror`, then the system forces a `break` (page 235).

`:error-restart` This means to *restart* the error. If the error was signalled by `cerror` and the error was restartable then the second value returned with `:error-restart` is thrown to the catch

tag `error-restart`. If the error was not restartable (always the case for errors signalled by `ferror`, then the system forces a `break` (page 235). An error may also be simply restarted from the handler by throwing directly from there to a catch tag of `error-restart`, but that is not as bullet proof if the error wasn't in fact restartable.

No other values are legal as the first values returned by error handlers. For errors signalled by `ferror` or `cerror` illegal values will force a `break`.

21.4. Signalling Errors

LISP programs can signal errors by using one of the functions `ferror` (for *fatal error*) or `cerror` (for continuable *error*).

`ferror` *condition-name control-string* `&rest` *params* [*Function*]

`ferror` signals the error condition *condtition-name*. The associated error message is obtainable by calling `format` (page 231) on *control-string* and *params*. The error is neither proceedable nor restartable. Function `ferror` never returns. It can be thrown through however. A usual COMMON LISP environment will have some sort of error handler established for condition name `t`. Thus the user can get at least minimal error handling with `ferror` using a null *condition-name* knowing that the error will at least be signalled to the user console.

`cerror` *proceedable-flag restartable-flag condition-name control-string* `&rest` *params* [*Function*]

`cerror` is similar to `ferror` (see above) except for *proceedable-flag* and *restartable-flag*. These are passed through to the eventual error handler. If `cerror` is called with a non-`()` *proceedable-flag* the caller should be prepared to accept the returned value of `cerror` and use it to retry the operation that failed. If `cerror` is passed a non-`()` *restartable-flag* then there should be a catch for taf `error-restart` somewhere above the caller.

`error-restart` {*form*}* [*Macro*]

`error-restart` can be used to denote a section of a program that can be restarted if certain errors occure during its execution. The form of an `error-restart` is:

For example:

```
(error-restart
  form1
  form2
  ...
  formn)
```

The expressions *formj* are evaluated in order; the values of all but the last are discarded (that is, the body of the `error-restart` form is an implicit `progn`). The value of the `error-restart` form is the value of *formn* (if the body is empty, `()` is the value). If a *restartbale* error occurs during the evaluation of one of the *formj*'s, and the handler responds by forcing a a restart, then the forms, beginning with *form1* will be re-evaluated in order. The only way a restartable error can occur is if

`cerror` is called with a *restartable-flag* which is non-`()`.

`error-restart` is implemented as a macro which expands into:

For example:

```
(prog ()
  loop (*catch 'error-restart
         (return (progn form1
                        form2
                        ...
                        formn)))
       (go loop))
```

`check-arg` *var-name predicate description type-name* [*Macro*]

The `check-arg` macro is used to check arguments to make sure they are valid, signal a `:wrong-type-argument` condition if they are not, and use the value returned by the handler to replace the invalid value.

var-name is the name of the variable whose value is being checked to be of the correct type. If the error is proceeded this variable will be `setq`'ed to a replacement value. *predicate* is a test for whether the variable is of the correct type. It can either be a symbol whose function definition takes one argument and returns non-`()` if the type is correct, or it can be a non-atomic form which is evaluated to check the type - usually such a form would contain a reference to the variable *var-name*. *description* is a string which expresses *predicate* in English. It is used in error messages. *type-name* gets passed to the `:wrong-type-argument` handler as the first required parameter of that class of error handlers (see section ??? <<<section ref "standard condition names">>>).

Thus `check-arg` has what consistitutes a valid argument specified to it in three ways. *predicate* is executable, *description* is human understandable and *type-name* is program understandable.

`check-arg` uses *predicate* to determine whether the value of the variable is of the correct type. If it is not a `:wrong-type-argument` condition is signalled with four parameters - *type-name*, the bad value, the symbol *var-name* and *description*. If the error is proceeded, the variable is set to the value returned and `check-arg` repeats the process. Only the first of these two parameters are defined for `:wrong-type-argument` handlers, and so theyt should not depend on the meanin of more than these two.

Consider for example:

For example:

```
(check-arg foo
           (and (fixnump foo) (< foo 0.))
           "a negative fixnum"
           negative-fixnum)
```

If `foo` is not of the right type an error will be signalled and a `:wrong-type-argument` which makes use of the *control-string* and *parameters* passed to it will print the message (at least):

```
Argument foo.was 33, which is not a negative fixnum.
```

21.5. Break-points

Often error handlers want to pass control to the user's terminal. The user can then examine variable bindings and respond to the error, or perhaps just start some new computation. Control is passed by using the special form `break`.

`break` *tag* [*conditional-form*] [*Special form*]

This enters a *breakpoint* loop, which is similar to a LISP top level loop. (`break` *tag*) will always enter the loop; (`break` *tag conditional-form*) will evaluate *conditional-form* and only enter the break loop if it returns non-( ). If the break loop is entered, `break` prints out

For example:

```
;bkpt tag
```

and then enters a loop reading, evaluating, and printing forms. After reading a form `break` checks for the following special cases. If the symbol `<altmode>p` is typed, `break` return ( ). If the the symbol `<altmode>r` is typed, `break` throws to a catch tag `error-restart`. If the symbol `<altmode>g` is typed, `break` throws back to the LISP top level. If (`return` *form*) is typed, `break` evaluates *form* and returns the result. In other respects a break loop appears very simialr to a top level loop.

21.6. Standard Condition Names

Some condition names are used by the COMMON LISP system itself. They are listed below along with the arguments they expect and the conventions followed in use of these conditions. All error condition handlers expect at least four arugments: *condition-name*, *control-string*, *proceedbale-flag*, and *restartable-flag*. In addition some condition names expect particular values for the fifth and subsequent arguments. These are included in the list below. It is always permissible to supply even more arguments than those required.

*** this list is not yet complete ***

`:wrong-type-argument`

Requires *type-name* and *value*, where the first is a symbol indicating what type of value is required, and the second is the bad value supplied to the fnction signalling the error. If the error is proceeded, the value returned by the handler (that is, the second value returned; the first would be `:return`) should be a new value for the argument to be used instead of the one which was of the wrong type.

`:inconsistent-arguments`

Requires *list-of-inconsistent-argument-values*. This condition is signalled when the arguments to a function are inconsistent with each other, but the fault does not lie with any particular one of them. If the error is proceeded, the value returned by the handler should

be returned by the function whose arguments were inconsistent.

Chapter 22

The Compiler

The compiler is a program which makes code run faster, by translating programs into an implementation-dependent form (subrs) which can be executed more efficiently by the computer. Most of the time you can write programs without worrying about the compiler; compiling a file of code should produce an equivalent but more efficient program. When doing more esoteric things, one may need to think carefully about what happens at "compile time" and what happens at "load time". Then the difference between the syntaxes "`#.`" and "`#,`" becomes important, and the `eval-when` (page EVAL-WHEN-FUN) construct becomes particularly useful.

Most declarations (see ???) are not used by the COMMON LISP interpreter; they may be used to give advice to the compiler. The compiler may attempt to check your advice and warn you if it is inconsistent.

Unlike most other LISP dialects, COMMON LISP recognizes `special` declarations in interpreted code as well as compiled code. This potential source of incompatibility between interpreted and compiled code is thereby *eliminated* in COMMON LISP.

The internal workings of a compiler will of course be highly implementation-dependent. The following functions provide a standard interface to the compiler, however.

`compile` *name* `&optional` *definition* [*Function*]

If *definition* is supplied, it should be a lambda-expression, the interpreted function to be compiled. If it is not supplied, then *name* should be a symbol with an interpreted-code definition; that definition is compiled.

The definition is compiled and a subr object produced. If *name* is a symbol, then the subr object is installed as the global function definition of the symbol and the symbol is returned. If *name* is `()`,then the subr object itself is returned.

For example:

```
(defun foo ...) => foo                    ;A function definition.
(compile 'foo) => foo                     ;Compile it.
        ;Now foo runs faster.
(compile () '(lambda (a b c) (- (* b b) (* 4 a c))))
  =>. a compiled function of three arguments which computes b^2-4ac
```

print *object* &optional *output-stream* [*Function*]
princ *object* &optional *output-stream* [*Function*]
ouch *character* &optional *output-stream* [*Function*]
tyo *integer* &optional *output-stream* [*Function*]
terpri &optional *output-stream* [*Function*]
fresh-line &optional *output-stream* [*Function*]
force-output &optional *output-stream* [*Function*]
clear-output &optional *output-stream* [*Function*]
format *destination control-string* &rest *arguments* [*Function*]
y-or-n-p &optional *message stream* [*Function*]
yes-or-no-p &optional *message stream* [*Function*]
fquery *options format-string* &rest *format-args* [*Function*]
standard-input [*Variable*]
standard-output [*Variable*]
error-output [*Variable*]
query-io [*Variable*]
terminal-io [*Variable*]
trace-output [*Variable*]
make-synonym-stream *symbol* [*Function*]
make-broadcast-stream &rest *streams* [*Function*]
make-concatenated-stream &rest *streams* [*Function*]
make-io-stream *input-stream output-stream* [*Function*]
make-echo-stream *input-stream output-stream* [*Function*]
make-string-input-stream *string* [*Function*]
make-string-output-stream &optional *line-length* [*Function*]
get-output-stream-string *string-output-stream* [*Function*]
streamp object [*Function*]
input-stream-p *stream* [*Function*]
output-stream-p *stream* [*Function*]
close *stream* &optional *abort-flag* [*Function*]
namelist *filespec* [*Function*]
namestring *filespec* [*Function*]
file-namestring *filespec* [*Function*]
directory-namestring *filespec* [*Function*]
host-namestring *filespec* [*Function*]
enough-namestring *filespec defaults* [*Function*]
parse-namestring *string* &optional *break-characters start end* [*Function*]
truename *file-stream* [*Function*]
mergef *filespec1 filespec2* [*Function*]
file-name-type *filespec* [*Function*]
file-name-version *filespec* [*Function*]
merge-file-name-type *type filespec* [*Function*]
merge-file-name-version *version filespec* [*Function*]

`with-open-file` *bindspec* {*form*}* [*Special form*]
`open` *filename* `&optional` *options* [*Function*]
`renamef` *file new-name* `&optional` *error-p* [*Function*]
`deletef` *file* `&optional` *error-p* [*Function*]
`probef` *filename* [*Function*]
`faslp` *file* `&optional` *implementation* [*Function*]
`file-creation-date` *file* [*Function*]
`file-author` *file* [*Function*]
`filepos` *file-stream* `&optional` *position* [*Function*]
`lengthf` *file-stream* [*Function*]
`load` *filename* `&optional` *package nonexistent-ok do-not-set-default* [*Function*]
`readfile` `&optional` *filename package no-msg-p* [*Function*]
`fasload` *filename* `&optional` *package no-msg-p* [*Function*]
`signal` *condition-name* `&rest` *args* [*Function*]
`condition-bind` *bindings* {*form*}* [*Special form*]
`condition-setq` {*spec*}* [*Special form*]
`ferror` *condition-name control-string* `&rest` *params* [*Function*]
`cerror` *proceedable-flag restartable-flag condition-name control-string* `&rest` *params* [*Function*]
`error-restart` {*form*}* [*Macro*]
`check-arg` *var-name predicate description type-name* [*Macro*]
`break` *tag* [*conditional-form*] [*Special form*]
`compile` *name* `&optional` *definition* [*Function*]
`comfile` *input-filespec* `&optional` *output-filespec* [*Function*]
`disassemble` *name-or-subr* [*Function*]

(End of COMMON LISP summary.)

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