Lisp Quickstart

Lisp is a big and deep language. This quickstart is only intended to get you introduced to very basic concepts in Lisp, not any of the really cool stuff Lisp does. As such it's geared to how to do C in Lisp, not good functional style (no closures, no macros). It's enough to get you up to speed so you can more easily understand a good book (ANSI Common Lisp, etc.) The quickstart also does not teach many functions -- you'll need to root around in the ANSI Common Lisp index and play with some of the functions there. The quickstart also shows you how to manipulate the command line, and to load and compile files.

Don't be intimidated by the size of this file. Just go through it at your own pace. We'll be teaching this stuff on the board anyway.

If you're done with this tutorial, go on to Tutorial 2 and Tutorial 3.

Legend

The table cell to the right shows what you type, and the output, for this tutorial. Text shown in blue you are responsible for typing, with a Return at the end of the line. Text shown in black indicates stuff that is printed back to you. Text shown in red are remarks -- do not type them. If the cell is divided by a line, as is shown at right, then this indicates two different examples.	This text is being printed out. You would type this text [This is a remark] Here is another example.

Running, Breaking, and Quitting Lisp

On osf1 or mason2, you start lisp by typing **lisp** at the command line. This fires up an implementation of lisp by Xanalys called LispWorks. If you've downloaded clisp or are using clisp on the ITE cluster, you typically start it by typing **clisp** and this is what you see:	[On osf1...] osf1.gmu.edu> lisp LispWorks(R): The Common Lisp Programming Environment Copyright (C) 1987-1998 Xanalys Incorporated. All rights reserved. Version 4.1.20 Saved by root as lispworks, at 29 May 2001 16:35 User sluke on osf1.gmu.edu ; Loading text file /usr/local/lispworks_4.1/hcl/4-1-0-0/ config/siteinit.lisp CL-USER 4 > --- [On chrono...] chrono[~]> clisp i i i i i i i ooooo o ooooooo ooooo ooooo I I I I I I I 8 8 8 8 8 o 8 8 I \ `+' / I 8 8 8 8 8 8 \ `-+-' / 8 8 8 ooooo 8oooo `-__|__-' 8 8 8 8 8 | 8 o 8 8 o 8 8 ------+------ ooooo 8ooooooo ooo8ooo ooooo 8 Copyright (c) Bruno Haible, Michael Stoll 1992, 1993 Copyright (c) Bruno Haible, Marcus Daniels 1994-1997 Copyright (c) Bruno Haible, Pierpaolo Bernardi, Sam Steingold 1998 Copyright (c) Bruno Haible, Sam Steingold 1999-2001 [1]>
In the previous examples, the very last line is the **command line**. Lisp has a command line where you type in things to execute. Here are the command lines in Lispworks and in clisp.	[On osf1...] CL-USER 4 > --- [On chrono...] [1]>

Think of the Lisp command line like the command line in a Unix shell or at a DOS prompt. Pressing Control-C in a Unix shell or at a DOS prompt halts the current running process and returns you to the command line. Similarly, pressing Control-C in Lisp halts whatever is presently running and returns you to the command line.

After you press Control-C, the command line changes to a "subsidiary" command line to reflect that you are in a **break condition**. Kinda like pressing Control-C in a debugger. In LispWorks, the break condition is signified by a colon in the command line. In clisp, the break condition is signified by the word "Break" in the command line.

You don't have to escape out of a break condition -- you can just keep on working from there. But it's probably best to escape out. On LispWorks, this is done by typing **:top** (including the colon). On clisp, this is done by repeatedly typing **:a** (including the colon) until you get out of the "Break" command line. In this example (and usuallly) you only need to type it once.

```
[On osf1...]
CL-USER 4 > (loop)              [Press Return at this point,
                                 and you go into an infinite loop]

                                [Now press Control-C, and you get...]

Break.
  1 (continue) Return from break.
  2 (abort) Return to level 0.
  3 Restart top-level loop.

Type :b for backtrace, :c <option number> to proceed,
or :? for other options

CL-USER 5 : 1 > :top

CL-USER 6 >
```

```
[On chrono...]
[1]> (loop)                     [Press Return at this point,
                                 and you go into an infinite loop]

                                [Now press Control-C, and you get...]


** - Continuable Error
EVAL: User break
If you continue (by typing 'continue'): Continue execution
1. Break [2]> :a

[3]>
```

You can quit your lisp session by getting to the command line (possibly through pressing Control-C), **then** typing **(quit)** and pressing return. Here are examples using Lispworks or using clisp.

```
[On osf1...]
CL-USER 4 > (quit)
osf1.gmu.edu>
```

```
[On chrono...]
[1]> (quit)
Bye.
chrono[~]>
```

Evaluating Simple Expressions

From now on, we will only use examples in **clisp**. But it works basicallly the same on all Lisp systems.

An **expression** is something that is **evaluated**, by which we mean, submitted to Lisp and executed. All things that are evaluated will return a **value**. If you type in an expression at the command line, Lisp will print its value before it returns the command line to you.

Numbers are expressions. **The value of a number is itself.** Lisp can represent a great many kind of numbers: integers, floating-point expressions, fractions, giant numbers, complex numbers, etc.

A fraction is straightforwardly represented with the form **x/y** Note that here the / does *not* mean "divide".

A complex number *a*+*b*i takes the form **#C(*a b*)**

```
[3]> -3
-3
[4]> 2.43
2.43
[5]> 12334230392341232341132323401292349234123123023492341023923441231233423039234123234113232340129234923412312302349234102392344123
[6]> #C(3.2 2)              [the complex number 3.2 + 2i ]
#C(3.2 2)
[7]> 2/3                    [the fraction 2/3.  NOT "divide 2 by 3"]
2/3
[8]> -3.2e25                [the number -3.2 x 10^25]
-3.2E25
[9]>
```

Individual **characters** are expressions. Like a number, the value of a character is itself. A character is represented using the #\ syntax. For example, **#\A** is the character 'A'. **#\%** is the character '%'.

Control characters have very straightforward formats:

```
[3]> #\g
#\g
[4]> #\{
#\{
[5]> #\space
#\Space
[6]> #\newline
```

#\tab
#\newline
#\space
#\backspace
#\escape

(etc.)

```
#\Newline
[7]> #\\       [The character '\']
#\\
[8]>
```

Strings are expressions. Just like a numbers and characters, the value of a string is itself.

A Lisp string is a sequence of characters. Lisp strings begin and end with double-quotes. Unlike in C++ (but like Java) a Lisp string does **not** terminate with a **\0**.

Like C++ and Java, Lisp strings have an escape sequence to put special characters in the string. The escape sequence begins with the backslash \ . To put a double-quote in the middle of a string, the sequence is **\"** To put a backslash in the middle of a string, the sequence is \\ Lisp tries to return values in a format that could be typed right back in again. Thus, it will also print return values with the escape sequences shown.

Unlike C++, you do not normally add returns and tabs to strings using an escape sequence. Instead, you just type the tab or the return right in the string itself.

```
[14]> "Hello, World!"
"Hello, World!"
[15]> "It's a glorious day."
"It's a glorious day."
[16]> "He said \"No Way!\" and then he left."
"He said \"No Way!\" and then he left."
[17]> "I think I need a backslash here:  \\  Ah, that was better."
"I think I need a backslash here:  \\  Ah, that was better."
[18]> "Look, here are      tabs      and some

returns!

Cool, huh?"
"Look, here are      tabs      and some

returns!

Cool, huh?"
[19]>
```

In Lisp, the special constant **nil** (case insensitive) all by itself represents "false". **nil** evaluates to itself.

Every other expression but nil is considered to be "true". However, Lisp also provides an "official" constant which represents "true", for your convenience. This is **t** (also case-insensitive). **t** also evaluates to itself.

```
[3]> t
T
[4]> nil
NIL
[5]>
```

Evaluating Lists as Functions

Lisp program code takes the form of **lists**. A list begins with a parenthesis, then immediately contains a **symbol**, then zero or more expressions separated with whitespace, then a closing parenthesis.

We'll discuss the format of symbols further down. In the examples at right, + and * are symbols, and denote the addition and multiplication functions respectively.

```
[14]> (+ 3 2 7 9)       [add 3+2+7+9 and return the result]
21
[15]> (* 4 2.3)     [multiply 4 by 2.3 and return the result]
9.2
```

Like everything else in Lisp, **lists are expressions**. This means that lists return a value when evaluated.

An **atom** is **every expression that is not a list**. Among other things, strings and numbers and boolean values are atoms.

When Lisp evaluates a list, it first examines (but **does not evaluate**) the symbol at the beginning of the list. Usually this symbol is associated with a **function**. Lisp looks up this function.

Then each expression in the list (except the beginning symbol) is evaluated **exactly once, *usually* (but not necessarily) left-to-right**.

The values of these expressions are then passed in as

```
[14]> (+ 3 2)     [Look up the + function, evaluate
                   3 and 2 (numbers evaluate to themselves),
                   then pass their values (3 and 2) into the
                   + function, which returns 5,
                   which is then returned].
5
[15]> (subseq "Hello, World" 2 9)     [Look up the subseq function,
                                       evaluate "Hello, World", 2,
                                       and 9 (they evaluate to
                                       themselves), then pass their
                                       values in as arguments.  The
                                       subseq function will return
                                       the substring in "Hello, World"
                                       starting at character #2 and
                                       ending just before character #9.
"llo, Wo"
```

parameters to the function, and the function is called. The list's return value is then the value returned by the function.

A **symbol** is a series of characters which typically do not contain whitespace, parentheses ( ), pound (#), quote ('), double-quote ("), period (.), or backquote (`), among a few others. Symbols generally don't take the form of numbers. It's very common for symbols to have hyphens (-) or asterisks (*) in them -- that's perfectly fine. **Symbols are case-INSENSITIVE**. Here are some interesting symbols:

\+ * 1+ / string-upcase
reverse length sqrt

Guess what function is associated with each of these symbols.

In C++ and in Java, there are operators like `+`, `<<`, `&&`, etc. But in Lisp, there are no operators: instead, there are only functions. For example, + is a function.

```
[23]> (+ 27/32 32/57)
2563/1824
[24]> (* 2.342 3.2e4)
74944.0
[25]> (* 2.342 9.212 -9.23 3/4)      [You can mix number types]
-149.34949
[26]> (/ 3 5)
3/5                  [The return type stays as general as possible]
[27]> (/ 3.0 5)
0.6                  [Here Lisp had no choice: convert to a float]
[28]> (1+ 3)
4
[29]> (string-upcase "How about that!")
"HOW ABOUT THAT!"
[30]> (reverse "Four score and seven years ago")
"oga sraey neves dna erocs ruoF"
[31]> (length "Four score and seven years ago")
30
[32]> (sqrt 2)
1.4142135
[33]> (sqrt -1.0)
#C(0 1.0)
[34]> (SqRt -1.0)     [Lisp symbols are case-insensitive]
#C(0 1.0)
```

While some functions require a fixed number of arguments, other ones (like + or *) can have any number of arguments.

```
[23]> (+ 100 231 201 921 221 231 -23 12 -34 134)
1994
```

Other functions have a fixed number of arguments, plus an *optional argument* at the end.

For example, **subseq** takes a string followed by one *or* two numbers. If only one number *i* is provided, then **subseq** returns the substring starting a position *i* in the string and ending at the end of the string.

If two numbers *i* and *j* are provided, then **subseq** returns the substring starting a position *i* in the string and ending at position *j*.

```
[23]> (subseq "Four score and seven years ago" 9)
"e and seven years ago"
[24]> (subseq "Four score and seven years ago" 9 23)
"e and seven ye"
```

Lisp has a special name for functions which return "true" (usually **t**) or "false" (**nil**). These functions are called **predicates**. Traditionally, many Lisp predicate names end with a **p**. Here are some predicates.

```
[5]> (= 4 3)               [is 4 == 3 ? ]
NIL
[6]> (< 3 9)               [is 3 < 9 ?]
T
[7]> (numberp "hello")     [is "foo" a number?]
NIL
[8]> (oddp 9)              [is 9 an odd number?]
T
[9]>
```

When an expression is evaluated which generates an error, Lisp breaks and returns to the command prompt with a break sequence, just like what happens when you press Control-C.

```
[26]> (/ 1 0)

*** - division by zero
1. Break [27]> :a       [clisp's way of exiting a break sequence]
[28]>
```

Errors can also occur if there is no function associated with a given symbol in a list.

```
[26]> (blah-blah-blah 1 0 "foo")

*** - EVAL: the function BLAH-BLAH-BLAH is undefined
1. Break [27]> :a
[28]>
```

When a list contains another list among its expressions, **the evaluation procedure is recursive**. The example at left thus does the following things:

1. The + function is looked up.
2. 33 is evaluated (its value is 33).

```
[44]> (+ 33 (* 2.3 4) 9)
51.2
[45]>
```

3. `(* 2.3 4)` is evaluated:
    1. The * function is looked up.
    2. 2.3 is evaluated (its value is 2.3)
    3. 4 is evaluated (its value is 4)
    4. 2.3 and 4 are passed to the * function.
    5. The * function returns 9.2. This is the value of `(* 2.3 4)`.
4. 9 is evaluated (its value is 9).
5. 33, 9.2, and 9 are passed to the + function.
6. The + function returns 51.2. This is the value of `(+ 33 (* 2.3 4) 9)`.
7. The Lisp system returns 51.2.

Here are some more examples.

Now you see how easy it is to get lost in the parentheses!

```
[44]> (+ (length "Hello World") 44)
55
[45]> (* (+ 3 2.3) (/ 3 (- 9 4)))    [in C++: (3+2.3) * (3 / (9-4)) ]
3.1800003
[46]> (log (log (log 234231232234234123)))
1.3052895
[47]> (+ (* (sin 0.3)
            (sin 0.3))          [expressions may use multiple lines]
         (* (cos 0.3)
            (cos 0.3)))         [ sin(0.3)^2 + cos(0.3)^2 ]
1.0000001                       [ = 1.  Rounding inaccuracy]
[48]> (and (< 3 (* 2 5))
           (not (>= 2 6)))      [ (3 < 2 * 5) && !(2 >= 6) ]
T
[49]>
```

One particularly useful function is **print**, which takes the form **(print *expression-to-print*)**. This function evaluates its argument, then prints it, then **returns the argument.**

As can be seen at right, if you just use **print** all by itself, the screen will appear to print the element twice. Why is that? It's because **print** printed its argument, then returned it, and Lisp always prints [again] the final return value of the expression.

One nice use of **print** is to stick it in the middle of an expression, where it will print elements without effecting the final return value of the whole expression.

```
[41]> (print (+ 2 3 4 1))
10
10
[42]> (print "hello")
"hello"
"hello"
[43]> (+ (* 2 3) (/ 3 2) 9)
33/2
[44]> (+ (print (* 2 3)) (print (/ 3 2)) 9)
6
3/2
33/2
[45]>
```

Control Structures and Variables

There are some evaluatable lists which are **not functions** because they do not obey the function rule ("evaluate each argument exactly one time each"). These lists are known as **macros** or **special forms**. For now we will not distinguish between these two terms, though there is a massive difference underneath.

Macros and special forms are mostly used as control structures. For example, the control structure **if** is a special form. **if** takes the form:

```
(if test-expression
    then-expression
    optional-else-expression)
```

if evaluates *test-expression*. If this returns true, then **if** evaluates and returns *then-expression*, else it evaluates and returns *optional-else-expression* (or if *optional-else-expression* is

```
[44]> (if (<= 3 2) (* 3 9) (+ 4 2 3))   [if 3<=2 then return 3*9
                                             else return 4+2+3]
9
[45]> (if (> 2 3) 9)    [if 2>3 then return 9 else return nil]
NIL
[46]> (if (= 2 2) (if (> 3 2) 4 6) 9)      [if 2==2,
                                               then if 3>2,
                                                       then return 4
                                                       else return 6
                                               else return 9]
4
[47]> (+ 4 (if (= 2 2) (* 9 2) 7))    [NOTE: the 'if' evaluates to 18!]
22
```

missing, returns nil).

Because **if** is an expression, unlike most languages it's quite common to see it embedded inside other expressions (like the last expression at right). This is roughly equivalent to C's ***i*?*j*:*k*** expression form.

Why can't **if** be a function? Because it may not necessarily evaluate the *then-expression*, or if it does, it will not evaluate the *optional-else-expression*. Thus it violates the function rule.

if only allows one test-expression, one then-expression, and one optional-else-expression. What if you want to do three things in the then-expression? You need to make a **block** (a group of expressions executed one-by-one). Blocks are made with the special form **progn**, which takes the form:

(progn *expr1 expr2 expr3 ...*)

progn can take any number of expressions, and evaluates each of its expressions in order. **progn** then returns the value of the last expression.

```
[44]> (if (> 3 2)
          (progn (print "hello") (print "yo")
                 (print "whassup?") 9)
          (+ 4 2 3))
"hello"
"yo"
"whassup?"
9
```

Except when they're at the head of a list, **symbols are also expressions**. When it's not the head of a list, a symbol **represents a variable**. When evaluated, a symbol will return the value of a variable.

The value of a symbol's variable **has nothing to do** with the function, special form, or macro associated with the symbol. You can thus have variables called **print**, **if**, etc.

Variables are set with the macro **setf**. For now, as far as you're concerned, this macro looks like this:

(setf *variable-symbol expression*)

setf is a macro and not a function because it does not evaluate *variable-symbol*. Instead, it just evaluates *expression*, and stores its value in the variable associated with *variable-symbol*. Then it returns the value of *expression*.

If a symbol is evaluated before anything has been stored in its variable, it will generate an error.

Be careful with **setf**. Lisp doesn't need to declare variables before they are used. Therefore, unless variables are declared to be local (discussed later), **setf** will make **global variables**. And **setf** is the first operation we've seen with side effects -- so the order of operations will matter! See the example at right.

```
[27]> (setf x (* 3 2))
6
[28]> x
6
[29]> (setf y (+ x 3))
9
[30]> (* x y)
54
[31]> (setf sin 9)      [ you really can do this! ]
9
[32]> (sin sin)         [ huh! ]
0.4121185
[33]> z                 [ z not set yet ]

*** - EVAL: variable Z has no value
1. Break [34]> :a

[Keep in mind that + is a function, so in most lisp systems it evaluates its
arguments left-to-right.  So x is evaluated -- returning 6; then
(setf x 3) is evaluated, which sets x to 3 and returns 3; then
x is evaluated -- and now it returns 3.  So + will return 6+3+3]
[35]> (+ x (setf x 3) x)
12
[Just like in C++/Java:   x + (x = 3) + x ]
```

Because special forms and macros don't obey the function rule, they can take whatever syntax they like. Here is **let**, a special form which declares local variables:

(let (*declaration1 declaration2 ...*)
** *expr1***
** *expr2***

```
[1]> (setf x 4)             [x set globally]
4
[2]> (let ((x 3))           [x declared local]
       (print x)
       (setf x 9)           [the local x is set]
       (print x)
       (print "hello"))     [Why does "hello" print twice? Think.]
3
9
```

```
    ... )
```

let declares local variables with each *declaration*. Then it evaluates the expressions in order (as a block). These expressions are evaluated in the context of these local variables (the expressions can see them). **let** then gets rid of the local variables and returns the value of the **last expression**. Thus the local variables are only declared within the **scope** of the **let expression**.

A declaration takes one of two forms:

var	A symbol representing the variable. It is initialized to **nil**.
(var expr)	A list consisting of the variable symbol followed by an expression. The expression is evaluated and the variable is initialized to that value.

You can use **setf** to change the value of a local variable inside a **let** statement. You can also nest **let** statements within other **let** statements. Locally declared variables may shadow outer local and global variables with the same name, just as is the case in C++ and in Java.

```
"hello"
"hello"
[3]> x                [outside the let, we're back to global again]
4
[4]> (let ((x 3) (y (+ 4 9)))    [declare x and y locally]
        (* x y))
39
[5]> (let ((x 3))                [declare x locally]
        (print x)
        (let (x)                 [declare x locally again (nested)]
           (print x)
           (let ((x "hello"))    [declare x locally again! (nested)]
              (print x))
           (print x))
        (print x)
        (print "yo"))            [Why does "yo" print twice?]
3
NIL
"hello"
NIL
3
"yo"
"yo"
```

Another reason a list might be a special form or macro is because it **repeatedly evaluates** its arguments. One example is **dotimes**. This macro is an iterator (a looping control structure). Like most iterators in Lisp, **dotimes** requires a variable. Here's the format:

```
(dotimes (var high-val
               optional-return-val)
         expr1
         expr2
         ...)
```

Here, dotimes first evaluates the expression *high-val*, which should return a positive integer. Then it sets the variable *var* (which is a symbol, and is **not** evaluated) to 0. Then it evaluates the zero or more expressions one by one. Then it increments *var* by 1 and reevaluates the expressions one by one. It does this until *var* reaches *high-val*. At this time, *optional-return-val* is evaluated and returned, or nil is returned if *optional-return-val* is missing.

You don't need to declare the dotimes variable in an enclosing let -- dotimes declares the variable locally for you. The dotimes variable is local only to the dotimes scope -- when dotimes exits, the variable's value resumes its previous setting (or none at all).

```
[26]> (setf x 3)
3
[27]> (dotimes (x 4 "yo") (print "hello"))
"hello"
"hello"
"hello"
"hello"
"yo"
[28]> x
3                              [x was local in dotimes]
[29]> (setf bag 2)
2
[30]> (dotimes (x 6) (setf bag (* bag bag)))
NIL                            [No return expression was given]
[31]> bag
18446744073709551616           [ Understand why? ]
```

Writing Functions

In Lisp, functions are created by calling a **function-making macro**. This macro is called **defun**.

A simple version of **defun** takes the following general form:

```
[44]> (defun do-hello-world ( )
            "Hello, World!")  ["Hello, World!" is last expression]
DO-HELLO-WORLD
[45]> (do-hello-world)        [ No arguments ]
"Hello, World!"
```

```
(defun function-name-symbol
          (param1 param2 param3 ...)
    expr1
    expr2
    expr3
    ... )
```

defun builds a function of zero or more arguments of the local-variable names given by the parameter symbols, then evaluates the expressions one by one, then returns the value of the last expression. The name of the function is the function-name-symbol. **defun** defines the function, sets it to this symbol, then returns the symbol -- you rarely use the return value of **defun**.

At right is a really simple example: a function of no arguments which simply returns the string "Hello, World!".

Here are some examples with one, two, and three arguments but just one expression.

```
[44]> (defun add-four (x)
          (+ x 4))
ADD-FOUR
[45]> (add-four 7)
11
[46] (defun hypoteneuse (length width)
          (sqrt (+ (* length length)
                   (* width width))))
HYPOTENEUSE
[47]> (hypoteneuse 7 9)
11.401754
[48]> (defun first-n-chars (string n reverse-first)
          (if reverse-first      [if reverse-first is "true" ]
            (subseq (reverse string) 0 n)
            (subseq string 0 n)))

FIRST-N-CHARS
[49]> (first-n-chars "hello world" 5 nil)
"hello"
[50]> (first-n-chars "hello world" 5 t)
"dlrow"
[51]> (first-n-chars "hello world" 5 18)      [ 18 is "true"! ]
"dlrow"
```

Here are some examples with several expressions in the function Remember, the function returns the value of the last expression.

```
[44]> (defun print-string-stuff (string-1)
          (print string-1)
          (print (reverse string-1))
          (print (length string-1))
          string-1)  [ string-1 is returned ]
PRINT-STRING-STUFF
[45]> (print-string-stuff "Hello, World!")
"Hello, World!"
"!dlroW ,olleH"
13
"Hello, World!"
[46] (setf my-global-counter 0)
0
[47] (defun increment-global-and-multiply (by-me)
          (setf my-global-counter (1+ my-global-counter))
          (* my-global-counter by-me))
INCREMENT-GLOBAL-AND-MULTIPLY
[48]> (increment-global-and-multiply 3)
3
[49]> (increment-global-and-multiply 5)
10
[50]> (increment-global-and-multiply 4)
12
[51]> (increment-global-and-multiply 7)
28
```

Lisp functions can have local variables, control structures, whatnot. Try to use local variables rather than global variables! Declare local variables with **let**.

```
[ In C++: long factorial (long n) {
              long sum = 1;
              for (int x=0;x<n;x++)
                  sum = sum * (1 + x);
              return sum; }            ]
[44]> (defun factorial (n)
          (let ((sum 1))
            (dotimes (x n)
              (setf sum (* sum (1+ x))))
            sum))
FACTORIAL
 [ ... but try doing *this* with C++ :-)  ]
```

```
[45]> (factorial 1000)
402387260077093773543702433923003985719374864210714632543799
910429938512398629020592044208486969404800479988610197196058631
666872994808558901323829669944590997424504087073759918823627
727188732519779505950995276120874975462497043601418278094646
962910563938874378864873371191810458257836478499770124766328
983595573543251318532395846307555740911426241747434934755342
846576611667797396668820291207379143853719588249808126867838
745597317461360853795345242215865932019280908782973084313928
440328123155861103697680135730421616874760967587134831202547
589320767169132448426236131412508780208000261683151027341827
977047846358681701643650241536913982812648102130927612448963
992870511496497541990934222156683257208082133318611681155361
836546984046708975602900950537616475847728421889679646244945
607653534081989013854424879849599533191017233555566021394503
973628075013783761530712776192684903435262520001588853514733
611702103968175921510907788019393178114194545257223865541461
628921879602238389714760885062768629671466746975629112340824
920816015378088989396451826324367161676217916890977991190375
031274622289988005195444414282012187361745992642956581746628
029555702990243241531816172104658320367869061172601587835207
151628422554026517048330422614397428693306169089796848259012
458327168226458066526769958652682272807075781391858178889652
081643483448259932660433676601769996128318607883861502794659
513115655203609398818061213855860030143569452722420634463179
460594682573103790084024432438465657245014402821885252470935
906209290231364932734975655139587205596542287497740114133469
627154228458623773875382304838656889764619273838149001407673
446640259899490222221765904339901886018566526485061799702356
938970178600408118897299183110211712298459016419210688843871
185564612496079872290851929681937238864261483965738229112312
024186649353143970137428531926649875337218940694281434118520
580141233448280150513996942901534830776445690990731524332782
826986460278986432113908350621709500259738986355427719674282
248757586765752344220207573630569498825087968928162753848863
969099598262809561214509948717012445164612603790293091208890
694202851064018215439945715680594187274899809425474217358240
063677404595741785160829230135358081840096996372524230560855
937006242712434169090041536901059339838357779394109700277534
720000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000
000000
```

Actually, it is surprisingly rare in Lisp to have more than one expression in a function. Instead, expressions tend to get nested together. Lisp functions tend to take on **functional** form rather than **declarative** form. In C++ or Java, usually you set local variables a lot. In Lisp you don't -- you nest functions.

```
[ a declarative style -- yuck ]
[44]> (defun my-equation (n)
          (let (x y z)
            (setf x (sin n))
            (setf y (cos n))
            (setf z (* x y))
            (+ n z)))
MY-EQUATION
 [ ... a functional style  ]
[45]> (defun my-equation (n)
          (+ n (* (sin n) (cos n))))
MY-EQUATION
```

Like Java, Lisp is pass-by-value. The parameters of a function are considered to be local variables to that function, and can be set with **setf**. This does not change the values of things passed in.

```
[44]> (defun weird-function (n)
            (setf n 4)
            n)
WEIRD-FUNCTION
[45]> (setf abc 17)
17
[46]> (weird-function abc)
4
[47]> abc
17
```

You can also make recursive functions. Lisp style often makes heavy use of recursion.

You'll find that functional style and recursion together result in a need for very few local variables.

Here's the factorial function again, only done recursively.

```
[44]> (defun factorial (n)
          (if (<= n 0)
            1
            (* n (factorial (- n 1)))))

FACTORIAL
```

You can make functions with an optional argument using the special term **&optional**, followed by the optional parameter name, at the end of your parameter list.

If the optional parameter isn't provided when the function is called, then the parameter is set to **nil**.

```
[48]> (defun first-n-chars (string n &optional reverse-first)
          (if reverse-first
            (subseq (reverse string) 0 n)
            (subseq string 0 n)))

REVERSE-FIRST
```

Alternatively you can provide the default value to set the parameter to when it's not provided when the function is called. You can do this by following **&optional** not by a parameter name but by a list of the form **(*param-name default-value*)**

You can have only one optional parameter.

```
[49]> (first-n-chars "hello world" 5 nil)
"hello"
[50]> (first-n-chars "hello world" 5)  [ nil is default]
"hello"
[51]> (first-n-chars "hello world" 5 t)
"dlrow"
[52]> (defun multiply-then-maybe-add (x y &optional (z 0) )
         (+ (* x y) z))
MULTIPLY-THEN-MAYBE-ADD
[53]> (multiply-then-maybe-add 9 2)
18
[54]> (multiply-then-maybe-add 9 2 7)
25
```

Lisp can also have **keyword parameters**. These are parameters which can appear or not appear, or be in any order, because they're given names. Keyword parameters are very much like the <foo arg1=val arg2=val ... > arguments in the "foo" html tag.

Keyword parameters appear at the end of a parameter list, after the term **&key**. Similarly to optional arguments, each keyword parameter is either a parameter name (whose value defaults to **nil** if not passed in when the function is called) or is a list of the form **(*param-name default-value*)**

Keyword parameters may appear only at the end of the parameter list.

You pass a keyword parameter whose name is **foo** into a function by using the term **:foo** followed by the value to set **foo** to. Keyword parameters can be passed in in any order, but must appear at the end of the parameter list.

Though it's possible to have both keyword parameters and optional parameters in the same function, don't do it. Gets confusing.

Many built-in Lisp functions use lots of keyword parameters to "extend" them!

```
[48]> (defun first-n-chars (string n
                  &key reverse-first  nil by default
                       (capitalize-first t) )   t by default
         (let ((val (if capitalize-first
                        (string-upcase string)
                        string)))
           (if reverse-first
             (subseq (reverse val) 0 n)
             (subseq val 0 n))))
 [ take a while to understand the LET before going on... ]

FIRST-N-CHARS
[49]> (first-n-chars "hello world" 5 :reverse-first t)
"DLROW"
[50]> (first-n-chars "hello world" 5
           :reverse-first t :capitalize-first nil)
"dlrow"
[51]> (first-n-chars "hello world" 5
           :capitalize-first nil :reverse-first t )
"dlrow"
[52]> (first-n-chars "hello world" 5)
"HELLO"
[53]> (first-n-chars "hello world" 5 :capitalize-first nil)
"hello"
```

Lists and Symbols as Data

Lists are normally evaluated as function or macro calls. Symbols are normally evaluated as variable references. But they don't have to be. Lists and symbols are data as well!

The special form **quote** can be used to *bypass the evaluation of its argument*. **quote** takes a single argument, and instead of evaluating that argument, it simply returns the argument as you had typed it ... as data!

```
[48]> (quote (hello world 1 2 3))

(HELLO WORLD 1 2 3)
[49]> (quote (what is (going on) here?))
(WHAT IS (GOING ON) HERE?)
[50]> (quote my-symbol)
MY-SYMBOL
[51]> (quote (+ 4 (* 3 2 9)))
(+ 4 (* 3 2 9))
```

What is a symbol when used in data form? It's just itself. The symbol **foo** is just a thing that looks like **foo** (case insensitive of course). It is a data type like any other. You can set variables to it.

What is a list when used in data form? A list is a **singly-linked list**. It is a data type like any other. You can set variables to it. There are a great many functions which operate on lists as well.

first returns the first item in a list. The old name of **first** is **car**.

rest returns a list consisting of everything *but* the first item. It does not damage the original list. The old name of **rest** is **cdr**.

append hooks multiple lists together.

cons takes an item and a list, and returns a new list consisting of the

```
[48]> (setf my-variable (quote hello))

HELLO
[49]> my-variable    [ stores the symbol HELLO ]
HELLO
[50]> (setf my-variable (quote (hey yo yo)))
(HEY YO YO)
[51]> my-variable
(HEY YO YO)
[52]> (setf var2 (first my-variable))
HEY
[53]> (setf var3 (rest my-variable))
(YO YO)
[54]> (cons 4 (rest my-variable))
(4 YO YO)
[55]> (append my-variable (quote (a b c)) my-variable)
(HEY YO YO A B C HEY YO YO)
[56]> my-variable
(HEY YO YO)     [ See?  No damage ]
[57]> (quote "hello")
```

old list with the item tacked on the front.

```
"hello"     [ makes no difference ]
[58]> (quote 4.3)
4.3     [ makes no difference ]
```

quote is so common that there is a special abbreviation for it...a single quote at the beginning of the item:

```
'hello-there
```

...is the same as...

```
(quote hello-there)
```

Here's how it's done for lists:

```
'(a b c d e)
```

...is the same as...

```
(quote (a b c d e))
```

Here's a repeat of some the previous code, but with the abbreviation.

```
[48]> (setf my-variable 'hello)
HELLO
[50]> (setf my-variable '(hey yo yo))
(HEY YO YO)
[55]> (append my-variable '(a b c) my-variable)
(HEY YO YO A B C HEY YO YO)
[57]> '"hello"
"hello"     [ makes no difference ]
[58]> '4.3
4.3     [ makes no difference ]
```

Lists as data can of course contain sublists.

In data form, the first item of a list can be anything -- it's not restricted to be just a symbol.

```
[48]> '(123.32 "hello" (how are (you there)) a)
(123.32 "hello" (HOW ARE (YOU THERE)) A)
[49]> '(((wow)) a list consisting of a list of a list!)
(((WOW)) A LIST CONSISTING OF A LIST OF A LIST!)
```

nil isn't just "false". It's also the empty list, **'()**

```
[48]> '()
NIL
[49]> (rest '(list-of-one-thing))
NIL
[50]> (append '(list-of-one-thing) nil)
(LIST-OF-ONE-THING)
[51]> '(a b c () g h i)
(A B C NIL G H I)
```

Lists have a common control structure, **dolist**, which iterates over a list. The format of **dolist** is very similar to **dotimes**:

```
(dolist (var list-to-iterate-over
                optional-return-val)
        expr1
        expr2
        ...)
```

dolist evaluates the list-to-iterate-over, then one by one sets *var* to each element in the list, and evaluates the expressions. **dolist** then returns the optional return value, else **nil** if none is provided.

```
[48]> (dolist (x '(a b c d e))
        (print x))
A
B
C
D
E
NIL
[49]> (defun my-reverse (list)
        (let (new-list)   [initially nil, or empty list]
          (dolist (x list)
            (setf new-list (cons x new-list)))
          new-list))
MY-REVERSE
[50]> (my-reverse '(a b c d e f g))
(G F E D C B A)
```

Lists and strings share a common supertype, **sequences**.

There are a great many sequence functions. All sequence functions work on any kind of sequence (including strings and lists). Here are two sequence functions we've seen so far.

```
[48]> (reverse '(a b c d e))
(E D C B A)
[49]> (reverse "abcde")
"edcba"
[50]> (subseq "Hello World" 2 9)
"llo Wor"
[51]> (subseq '(yo hello there how are you) 2 4)
(THERE HOW)
```

Loading and Compiling Lisp

Lisp is both an **interpreter** and a **compiler**.

If you type in code at the command line, it is (on most Lisp systems)

```
[48]> (defun slow-function (a)
       (dotimes (x 100000)
          (setf a (+ a 1)))
```

interpreted.

You can compile a function by passing its symbol name (quoted!) to the **compile** function.

You can time the speed of any expression, and its garbage collection, with the **time** function.

```
       a)

SLOW-FUNCTION
[49]> (time (slow-function 0))

Real time: 1.197806 sec.
Run time: 1.15 sec.
Space: 0 Bytes
100000

[50]> (compile 'slow-function)
SLOW-FUNCTION ;
NIL ;
NIL

[51]> (time (slow-function 0))

Real time: 0.066849 sec.
Run time: 0.07 sec.
Space: 0 Bytes
100000
```

You don't have to type all your code in on the command line. Instead, put it in a file named **"myfile.lisp"** (or whatever, so long as it ends in ".lisp"). Then load it with the **load** command.

load works exactly as if you had typed in the code directly at the command line.

By default, **load** is fairly silent -- it doesn't print out all the return values to the screen like you'd get if you typed the code in at the command line. If you'd like to see these return values printed out, you can add the **:print t** keyword parameter.

You can load and reload files to your heart's content.

```
[ Make a file called "myfile.lisp", containing this: ]
(setf foo 3)
(defun my-func ()
       (print 'hello))
foo
(sin foo)
(my-func)
```

```
[ At the command line, you type: ]

[49]> (load "myfile.lisp")
;; Loading file myfile.lisp ...
HELLO      [ because we called (my-func), which printed ]
;; Loading of file myfile.lisp is finished.
T          [ load returns t ]

[ To get the return values for each item entered in:  ]

[50]> (load "myfile.lisp" :print t)
;; Loading file myfile.lisp ...
3
MYFUNC
3
0.14112
HELLO
HELLO
;; Loading of file myfile.lisp is finished.
T
```

You can also compile a whole file with the **compile-file** function.

When a file is compiled, the object file created has a **.fas** or **.fsl** or **.fasl** or **.afasl** extension. Depends on the Lisp compiler.

You load object files with the **load** function as well.

You can omit the extension (".lisp", ".afasl", etc.) from the filename, but what happens as a result is implementation-dependent. Some systems load the most recent version (either the source or the .afasl file); others may load the .afasl file always but warn you if there's a more recent .lisp file, etc. **In general, to be safe, always load the full name of the file including the extension.**

When the compiler compiles the file, one common thing it will complain of is **special variables**. For all intents and purposes, a special variable is a **global variable**. With very few exceptions, you should never use global variables when you can use local variables instead.

In our file we had declared a global variable (**foo**). Look at the warnings when we compile!

```
[18]> (compile-file "myfile.lisp")

Compiling file myfile.lisp ...
WARNING in function #:TOP-LEVEL-FORM-1 in line 1 :
FOO is neither declared nor bound,
it will be treated as if it were declared SPECIAL.
WARNING in function #:TOP-LEVEL-FORM-3 in lines 4..5 :
FOO is neither declared nor bound,
it will be treated as if it were declared SPECIAL.
WARNING in function #:TOP-LEVEL-FORM-4 in line 5 :
FOO is neither declared nor bound,
it will be treated as if it were declared SPECIAL.

Compilation of file myfile.lisp is finished.
The following special variables were not defined:
 FOO
0 errors, 3 warnings
#P"myfile.fas" ;
3 ;
3

[19]> (load "myfile.fas")
;; Loading file myfile.fas ...
HELLO
;; Loading of file myfile.fas is finished.
T
```

Lisp Style

As you can see, Lisp can get quite confusing because of the parentheses. How tedious it is reading code based on parentheses! That's why Lisp programmers don't do it.

Lisp programmers don't rely much on the parentheses when reading code. Instead, they rely heavily on breaking expressions into multiple lines and indenting them in a very peculiar way. There is a "cannonical" indent format and style for Lisp. Code which adheres to the standard format can be read very rapidly by Lisp programmers who have developed a "batting eye" for this format.

Important formatting rules:

- Put a single space between each item in a list.
- Do NOT put space between the opening parenthesis and the first item in a list. Similarly, do NOT put space between the closing parenthesis and the last item.
- Never put parentheses all by themselves on lines like a C++/Java brace. Do not be afraid to pile up parentheses at the end of a line.

Do NOT use simplistic editors like pico or Windows Notepad. You will regret it. Deeply. **Use an editor designed for Lisp.** Integrated Lisp systems (the big three are Franz Allegro Common Lisp, Xanalys Harlequin Common Lisp, and Macintosh Common Lisp) with graphical interfaces have built-in editors which will automatically indent text for you in the official style, will colorize your text, will tell you whether your syntax is right or not, and will match parentheses for you.

Another good choice, indeed the classic option in Lisp systems, is the editor **emacs**. It is written in its own version of Lisp, and is very good at editing Lisp code and working with Lisp systems, especially with an add-on Lisp-editing plug-in called **slime**. emacs is the program whose auto-indent facilities established the "cannonical" style of Lisp formatting.

If you can't find an editor which can do the cannonical style, there are still plenty of choices which do a reasonable job. Any professional-grade code editor will do in a pinch. Without a good editor, writing large Lisp programs is **painful**. GET A CODE EDITOR. You are an adult now, and will soon be a professional. Use real tools to get your job done.

[BAD Lisp Style Formatting Examples]

```
(if(< (* 3 4)5)(sin(+ 3 x) ) ( - x y ))


(If
    (<
       (* 3 4)
       5
    )
    (SIN
       (+ 3 x)
    )
    (- x y )
)
```

[A reasonably GOOD Lisp Style Formatting Example]

```
(if (< (* 3 4) 5)
      (sin (+ 3 x))
      (- x y))
```

[A more canonical Lisp Indent Format]

```
(if (< (* 3 4) 5)
    (sin (+ 3 x))
  (- x y))
```

Comments in Lisp are of three forms.

Winged comments (the equivalent of /* and */ in C++ or Java) begin with a #| and end with a |# They are not commonly used in Lisp except to temporarily eliminate chunks of code, because it's hard to tell they exist by examining your code.

Inline comments (the equivalent of // in C++ or Java) begin with a semicolon **;** and end with a return.

Many Lisp structures have built-in documentation comments. For example, if the first expression in a **defun** statement is a string, that string is not part of the code but instead is considered to be the "documentation" for the function. You can access the documentation for an object with the **documentation** function.

It is common in Lisp to pile up several semicolons **;;** or **;;;** to make the comment more visible.

Here is a common approach:

- Use one semicolon for inline code.
- Use two semicolons to comment the head of a function.

[A well-commented file]

```
;;; pi-estimation package
;;; Sean Luke
;;; Wednesday, 8/21/2002



;; ESTIMATE-PI will compute the value of pi to
;; the degree given, maintaining the value as a giant
;; fraction.  It uses the Leibniz (1674)
;; formula of pi = 4 * ( 1/1 - 1/3 + 1/5 - 1/7 + ...  )
;; degree must be an integer > 0.

(defun estimate-pi (degree)
  "Estimates pi using Leibniz's formula.
degree must be an integer greater than 0."
  (let ((sum 0) (inc 1))                ; inc goes 1, 5, 7, ...
    (dotimes (x degree (* 4 sum))       ; we return 4*sum
         #| (setf sum (+ sum (/ 1 inc))
                  (- 0 (/ 1 (+ inc 2)))) |#     ; yucky
      (setf sum (+ sum (/ 1 inc) (/ -1 (+ inc 2))))
      (setf inc (+ 4 inc)))))
```

[...after estimate-pi has been entered into Lisp...]

```
[13]> (documentation 'estimate-pi 'function)
"Estimates pi using Leibniz's formula.
degree must be an integer greater than 0."
```

- Use three semicolons to comment the head of a file or other big region.
- Use winged comments only to comment-out a region temporarily.

```
[14]> (describe 'estimate-pi)
[Get ready for more information than you really need!]

ESTIMATE-PI is the symbol ESTIMATE-PI, lies in
#<PACKAGE COMMON-LISP-USER>, is accessible in
the package COMMON-LISP-USER, names a function,
has the properties SYSTEM::DOCUMENTATION-STRINGS,
SYSTEM::DEFINITION.

Documentation as a FUNCTION:
Estimates pi using Leibniz's formula.
degree must be an integer greater than 0.
For more information, evaluate (SYMBOL-PLIST 'ESTIMATE-PI).

#<PACKAGE COMMON-LISP-USER> is the package
named COMMON-LISP-USER. It has the nicknames CL-USER,
USER.It imports the external symbols of the packages
COMMON-LISP, EXT and exports no symbols, but no
package uses these exports.

#<CLOSURE ESTIMATE-PI (DEGREE) (DECLARE #)
(BLOCK ESTIMATE-PI #)> is an interpreted function.
argument list: (DEGREE)
```

Lisp has important style rules about symbols, used for both variables and function names.

- Although Lisp symbols are case-insensitive, **ALWAYS use lower-case**. There is a good reason for this. Keep in mind that Lisp is an interactive system: both you and the system are producing text on the screen. Lisp systems spit out symbols in UPPER-CASE. By sticking with lower-case yourself, you can distinguish between the text you typed and the text the Lisp system generated.
- Do NOT use underscores in symbols. **Use hyphens.**
- Although the previous examples above didn't do it to avoid confusing you, you should always **denote global variables by wrapping them with *asterisks*.** Global variable names should also be self-explanatory.
- Variable names should be nouns.
- Function names should be verbs.
- Though you can always name variables the same names as functions, it's more readable not to do so.

```
[BAD Lisp Style Symbols:]
my_symbol_name
mySymbolName
MySymbolName
MY_SYMBOL_NAME


[A GOOD Lisp Style Symbol]
my-symbol-name



[A BAD Global Variable Name]
aprintf


[A GOOD Global Variable Name]
*alpha-print-format*
```

Lisp is a functional language. Learn to use functional style. One way you can tell you're using functional style is if you have *very* few (or even no) local variables, and rarely if ever use a global variable.

As Paul Graham says, "treat **setf** as if there were a tax on its use."

```
[HORRIBLE Lisp Style]

(defun do-the-math (x y z)
        (setf w (+ x y))
        (setf n (* z w))
        (+ x n))



[MERELY BAD Lisp Style -- no global variables]

(defun do-the-math (x y z)
        (let (w n)
                (setf w (+ x y))
                (setf n (* z w))
                (+ x n)))



[BETTER Lisp Style -- functional style]

(defun do-the-math (x y z)
  (+ x (* z (+ x y))))
```

Declare your global variables once with **defparameter** before you start using them in **setf** statements.

(defparameter ***var-symbol initial-value***

```
[13]> (defparameter *tuning-value* 4.0
      "The tuning value of the amplitude dial")
*TUNING-VALUE*
```

***optional-documentation-string*)**

Declare global constants with **defconstant**.

(defconstant ***var-symbol value***
***optional-documentation-string*)**

The documentation strings can be accessed via **documentation**, and of course, **describe**.

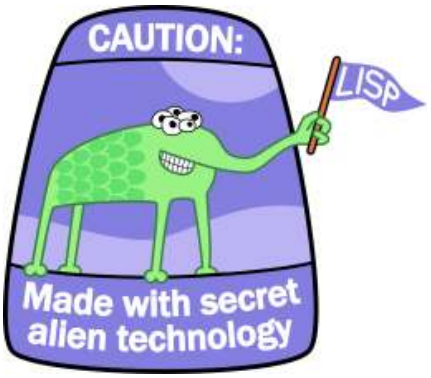
```
[14]> (defconstant *low-quality-pi* 3.14159
      "Pi to only six digits")
*LOW-QUALITY-PI*
[15]> (documentation '*tuning-value* 'variable)
"The tuning value of the amplitude dial"
[16]> (describe '*low-quality-pi*)

*LOW-QUALITY-PI* is the symbol *LOW-QUALITY-PI*,
lies in #<PACKAGE COMMON-LISP-USER>, is accessible
in the package COMMON-LISP-USER, a constant,
value: 3.14159, has the property SYSTEM::DOCUMENTATION-STRINGS.
Documentation as a VARIABLE:
Pi to only six digits
For more information, evaluate (SYMBOL-PLIST '*LOW-QUALITY-PI*).

#<PACKAGE COMMON-LISP-USER> is the package named
COMMON-LISP-USER. It has the nicknames CL-USER, USER.
It imports the external symbols of the packages
COMMON-LISP, EXT and exports no symbols, but no
package uses these exports.

3.14159 is a float with 24 bits of mantissa (single-float).
```

Lisp II



This tutorial will introduce you to more concepts in Lisp that weren't covered in the Quickstart. In addition to more data structures and control concepts, we'll get into basic concepts that really make Lisp different from other languages.

As before, the examples we give will be based on CLISP, but they work basically the same in all lisp systems.

You can go back to Tutorial 1 (QuickStart) or forward to Tutorial 3.

Legend

As before, the table cell to the right shows what you type, and the output, for this tutorial. Text shown in blue you are responsible for typing, with a Return at the end of the line. Text shown in black indicate stuff that is printed back to you. Text shown in red are remarks -- do not type them. If the cell is divided by a line, as is shown at right, then this indicates two different examples.	This text is being printed out. You would type this text [This is a remark] Here is another example.

Arrays and Vectors

Lisp has many kinds of arrays: multidimensional arrays, variable-length arrays, fixed-length simple arrays, arrays guaranteed to have certain types in them, arrays which can hold anything, etc. Lisp arrays are created with the function **make-array**. The simplest form of this function is: **(make-array *length*)** This form makes a one-dimensional fixed-length array *length* elements long. The elements are each initialized to **nil**. An array of this form is called a *simple-vector*. You don't just have to use **make-array** to build a simple-vector. Just as you can make a list of the symbols *a b c* by typing **'(a b c)**, you can make a simple vector of the symbols *a b c* by typing **#(a b c)**	[1]> (make-array 4) #(NIL NIL NIL NIL) [2]> #(a b c) #(A B C) [3]>
A multidimensional array is created as follows: **(make-array *dimension-list*)** This form makes an N-dimensional fixed-length array of the dimensions given by elements in the list. The elements are each initialized to **nil**. You can specify the initial value of the elements with the keyword **:initial-element**. The general function for extracting the element of	[1]> (make-array '(4 3 8)) [it has to be quoted] #3A(((NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL)) ((NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL)) ((NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL)) ((NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL) (NIL NIL NIL NIL NIL NIL NIL NIL))) [2]> (make-array '(2 2) :initial-element 0)

any array is **aref**. It takes the form:

(aref *array index1 index2 ...*)

Simple vectors have a special version, **svref**, which is slightly faster than **aref** (in fact, **aref** just calls **svref** for simple vectors):

(svref *simple-vector index*)

Lisp arrays are zero-indexed. This is just like saying (in C++/Java): **array[index1][index2]...**

Multidimensional arrays can also be specified with **#*n*A(...)**, where *n* is the number of dimensions. See the example at right.

```
#2A((0 0) (0 0))
[3]> (setf *j* #2A((1 2 3) (4 5 6)))
#2A((1 2 3) (4 5 6))
[4]> (aref *j* 1 1)
5
[5]> (aref #(a b c d e) 3)
D
[6]> (svref #(a b c d e) 3)  [ faster ]
D
```

Vectors are one-dimensional arrays. You've already seen fixed-length vectors (known in Lisp as *simple-vectors*). Lisp also has variable-length vectors.

Variable-length vectors are created with the keywords **:adjustable** and **:fill-pointer** in the following fashion:

(make-array *length* :fill-pointer t :adjustable t)

You can have a zero-length vector. It's very common to start a variable-length array at length 0.

You can tack new stuff onto the end of a variable-length vector with the command **vector-push-extend**. You can "pop" elements off the end of the variable-length vector with **vector-pop**.

To use these functions, the vector *must* be variable-length. You cannot push and pop to a simple vector.

Multidimensional arrays can also have their sizes adjusted. We'll just leave it at that -- look it up if you're interested.

```
[1]> (setf *j* (make-array 0 :fill-pointer t :adjustable t))
#()
[2]> (vector-push-extend 10 *j*)
0
[3]> (vector-push-extend 'hello *j*)
1
[3]> *j*
#(10 HELLO)
[3]> (aref *j* 1)
HELLO
[4]> (vector-pop *j*)
HELLO
[5]> *j*
#(10)
```

A string is, more or less, a vector of characters. You can access elements with **aref**. But because a string is *not* a simple vector (oddly enough), you *cannot* use **svref**. I have no idea why.

Although string elements can be accessed via **aref**, strings have their own special function which does the same thing: **char**, which takes the form:

(char *string index*)

In most systems, the two functions are about the same speed.

```
[1]> (aref "hello world" 3)
#\l
[2]> (char "hello world" 6)
#\w
```

Setf and Friends

setf doesn't just set variables. In general, **(setf *foo bar*)** "sees to it" that *foo* will evaluate to *bar*. **setf** can "see to" an amazing number of things.

To set the value of an element in an array (I bet you were wondering about that!) you say

(setf (aref *array indices...*) *val*)

You can do the same trick with **svref** and **char**.

You can also use **setf** to modify lists. However, this is dangerous if you don't know what you're doing. For now, don't do it. Stick with modifying arrays and strings.

```
[1]> (setf *j* #(a b c d e))
#(A B C D E)
[2]> (setf (svref *j* 3) 'hello)
HELLO
[3]> *j*
#(A B C HELLO E)
[4]> (setf *k* (make-array '(3 3 3) :initial-element 4))
#3A(((4 4 4) (4 4 4) (4 4 4))
    ((4 4 4) (4 4 4) (4 4 4))
    ((4 4 4) (4 4 4) (4 4 4)))[4]> (vector-pop *j*)
HELLO
[5]> (setf (aref *k* 2 1 1) 'yo)
YO
[6]> *k*
#3A(((4 4 4) (4 4 4) (4 4 4))
    ((4 4 4) (4 4 4) (4 4 4))
    ((4 4 4) (4 YO 4) (4 4 4)))
[7]> (setf *l* "hello world")
"hello world"
[8]> (setf (char *l* 4) #\B)
#\B
[9]> *l*
"hellB world"
```

A variant of **setf** called **incf** does more or less the same thing as the ++ operator in C++ or Java, except that it works on all sorts of things (array slots, etc.) in addition to just variables. The form:

(incf *expression* 4)

...will see to it that *expression* evaluates to 4 more than it used to (by adding 4 to it). If you just say:

(incf *expression*)

...this by default sees to it that *expression* evaluates to 1 more than it used to.

The macro **decf** does the opposite.

```
[1]> (setf *j* #(1 2 3 4 5))
#(1 2 3 4 5)
[2]> (incf (svref *j* 3) 4)
8
[3]> *j*
#(1 2 3 8 5)
[4]> (setf *k* 4)
4
[5]> (incf *k*)
5
[6]> *k*
5
[7]> (decf *k* 100)
-95
```

Another variant of **setf** called **push** can be used to "see to it" that an expression (which must evaluate to a list) now evaluates to a list with an element tacked onto the front of it. If you say:

(push *val expression*)

...this is roughly the same as saying

(setf *expression* (cons *val expression*))

You can also "see to it" that a list has an element removed from the front of it with **pop**:

(pop *expression*)

```
[1]> (setf *j* #((a b) (c d) (e f)))   [ a simple-vector of lists ]
#((A B) (C D) (E F))
[2]> (push 'hello (svref *j* 1))
(HELLO C D)
[3]> *j*
#((A B) (HELLO C D) (E F))
[4]> (setf *k* '(yo yo ma))
(YO YO MA)
[5]> (pop *k*)
YO
[6]> *k*
(YO MA)
```

Another useful variant, **rotatef**, can be used to swap several elements.

(rotatef *expresion1 expression2 ... expressionN*)

...this is roughly the same as saying

```
[1]> (setf *j* #(gracias senor))
#(GRACIAS SENOR)
[2]> (setf *k* 'hello)
HELLO
[3]> (rotatef (elt *j* 0) (elt *j* 1) *k*)
NIL
[4]> *j*
#(SENOR HELLO)
```

(setf *tempvar expression1*) **(setf *expression1 expression2*)** ... **(setf *expressionN-1 expressionN*)** **(setf *expressionN tempvar*)** A simple use of this is simply **(rotatef *expression1 expression2*)** which sees to it that the values of *expression1* and *expression2* are swapped.	[5]> *k* GRACIAS [6]> (setf *z* #(1 2 3 4 5)) #(1 2 3 4 5) [7]> (rotatef (elt *z* 1) (elt *z* 4)) [swap 'em] NIL [8]> *z* #(1 5 3 4 2)

Function, Funcall, and Apply

In Lisp, pointers to functions are first-class data objects. They can be stored in variables, passed into arguments, and returned by other functions. The special form **function** will return a pointer to a function. It takes the form **(function *function-symbol*)**. Notice that just like **quote**, **function** doesn't evaluate its argument -- instead it just looks up the function by that name and returns a pointer to it. Also like **quote**, **function** is so common that there is a shorthand for it: a pound sign followed by a quote at the beginning of the function name: **#'print** ...is the same as... **(function print)** Keep in mind that you can *only* get pointers to *functions*, not macros or special forms.	[1]> (function print) #<SYSTEM-FUNCTION PRINT> [2]> (function if) ["if" isn't a function -- it's a macro] *** - FUNCTION: undefined function IF 1. Break [3]> :a [4]> (setf *temp* (function *)) [the "*" function] #<SYSTEM-FUNCTION *> [5]> *temp* #<SYSTEM-FUNCTION *> [6]> #'print #<SYSTEM-FUNCTION PRINT> [7]> (setf *temp* #'*) #<SYSTEM-FUNCTION *> [8]> *temp* #<SYSTEM-FUNCTION *>
A common mistake among Lisp newbies is to think that variables with function pointers stored in them can be used to make a traditional function call by sticking the variable at the beginning of a list. Remember that the first item in an evaluated list must be a *symbol* which is *not evaluated*. If a variable could be put as the first item, it would have to be evaluated first (to extract the function pointer). Thus, Common Lisp can associate a *function* with a symbol (by using **defun**) and it can *also* associate a *value* with the same symbol as a variable (by using **setf**). A Lisp which can associate two or more different kinds of things at the same time with a symbol is called a **Lisp 2**. Common Lisp is a Lisp 2. Emacs Lisp is also a Lisp 2. Scheme, another popular Lisp dialect, evaluates the first item in the list as a *variable*, looking up its function-pointer value. Scheme associates only one thing with a symbol: the item stored in its variable. Thus Scheme is a **Lisp 1**.	[6]> (setf *new-print* (function print)) #<SYSTEM-FUNCTION PRINT> [7]> (*new-print* "hello world")> *** - EVAL: the function *NEW-PRINT* is undefined 1. Break [8]> :a [9]>

Lisp 1's are simpler and more intuitive than Lisp 2's. But it is more difficult to do certain kinds of powerful things with them, like macros. We'll get to that later on.

If you can't just call a function pointer by sticking it in the first spot in a list, how *do* you call it?

There are a great many functions and macros which use function pointers. One basic one is **funcall**. This function takes the form

(funcall *function-pointer arg1 arg2 ...*)

funcall is a function which evaluates *function-pointer*, which returns a pointer to a function, then it evaluates each of the arguments, then passes the argument values into the function. **funcall** returns the value of the function.

```
[6]> (setf *new-print* (function print))
#<SYSTEM-FUNCTION PRINT>
[7]> (funcall *new-print* "hello world")>

"hello world"
"hello world"
[8]> (funcall #'+ 1 2 3 4 5 6 7)
28
[9]> (funcall #'funcall #'+ 1 2 3 4 5 6 7) [hee hee!]
28
[10]>
```

Another useful function which takes function pointers is **apply**. The simple version of this function takes the form

(apply *function-pointer list-arg*)

apply takes a function pointer, plus one more argument which **must evaluate to a list**. It then takes each element in this list and passes them as arguments to the function pointed to by *function-pointer*. **apply** then returns the value the that the function returned.

It so happens that **apply** can do one additional trick. Alternatively, **apply** can look like this: **(apply *function-pointer arg1 arg2 ... list-arg*)**

The last argument **must evaluate to a list**. Here, **apply** builds a list before passing it to the function. This list is built by taking each of the *arg1, arg2,* arguments and concatenating their values to the front of the list returned by *list-arg*. For example, in **(apply #'+ 1 2 3 '(4 5 6))**, the concatenation results in the list **'(1 2 3 4 5 6)**. Thus

(apply #'+ 1 2 3 '(4 5 6)) is the same thing as

(apply #'+ '(1 2 3 4 5 6)) which is the same thing as

(apply #'+ 1 2 3 4 5 6 '()) which of course is the same thing as

(apply #'+ 1 2 3 4 5 6 nil)

```
[6]> (apply #'+ '(1 2 3 4 5 6))
21
[7]> (apply #'+ 1 2 3 4 5 6 nil)
21
[8]> (apply #'+ 1 2 3 '(4 5 6))
21
[9]> (apply #'apply #'+ '(1 2 3 (4 5 6)))    [woo hoo!]
21
[10]> (apply #'funcall #'+ '(1 2 3 4 5 6))   [yee haw!]
21
[11]> (funcall #'apply #'+ '(1 2 3 4 5 6))   [hmmmm...]
21
```

Mapping

Lisp uses pointers to functions *everywhere*. It's what makes Lisp's built-in functions so powerful:

```
[1]> (mapcar #'sqrt '(3 4 5 6 7))
(1.7320508 2 2.236068 2.4494898 2.6457512)
```

they take optional functions which let you customize the built-in ones in special ways.

One very common use of pointers to functions is *mapping*. Mapping applies a function repeatedly over one or more lists, resulting in a new list. The most common mapping function is **mapcar**, which in a basic form looks like this:

(mapcar *function-pointer list*)

Since we're providing just one list, *function-pointer* must be a pointer to a function which can take just one argument, for example, **sqrt**.

In this form, **mapcar** repeatedly applies the function to each element in the list. The return values are then put into a list and returned.

```
[2]> (mapcar (function print) '(hello there how are you))

HELLO
THERE
HOW
ARE
YOU
(HELLO THERE HOW ARE YOU)
[3]>
```

mapcar more generally looks like this:

(mapcar *function-pointer list1 list2* ...)

If *function-pointer* points to a function which takes *N* arguments, then we must provide *N* lists.

mapcar takes the first element out of each list and passes them as arguments to the function. **mapcar** then takes the second element out of each list and passes them as arguments to the function. And so on. **mapcar** then returns a list of the return values of the function.

If any list is shorter than the others, **mapcar** operates only up to the shortest list and then stops.

Lisp provides a number of other useful mapping functions: **map, mapc, mapcan, mapcon ...**

```
[1]> (mapcar #'/ '(1 2 3 4 5) '(7 8 9 10 11))
(1/7 1/4 1/3 2/5 5/11)
[2]> (mapcar #'* '(1 2 3 4)
           '(5 6) '(7 8 9))  [one list is only 2 long]
(35 96)
[3]>
```

A related feature is *reduction*: composing a function in on itself. The basic **reduce** function looks similar to **mapcar**:

(reduce *function-pointer list*)

function-pointer must point to a function which takes exactly *two arguments*. If the elements in *list* are *a b c d*, and the function *func* is stored in the function pointer, this is the same thing as doing:

(func (func (func a b) c) d)

You can also change the order of operations with the **:from-end t** keyword argument, resulting in the ordering:

(func a (func b (func c d)))

reduce has other gizmos available. Check 'em out.

```
[Note: (expt a b) computes a ^ b  (a to the power of b) ]
[1]> (reduce #'expt '(2 3 4 5))  [((2^3)^4)^5)]
1152921504606846976
[2]> (reduce #'expt '(2 3 4) :from-end t)    [2^(3^4)]
24178516392292583494123 52
[3]>
```

Lambda and Closures

A **lambda expression** is one of the more powerful concepts in Lisp. A lambda expression is an *anonymous function*, that is one that doesn't have a name -- just a pointer to it.

Lambda expressions are created using the form:

```
(function (lambda (args...) body...))
```

Note how similar this is to **defun**:

```
(defun function-name (args...) body...)
```

A lambda expression builds a function just like **defun** would, except that there's no name associated with it. Instead, the lambda expression returns a pointer to the function.

Remember that **function** has a shorthand of **#'** so the lambda expression is usually written like this:

```
#'(lambda (args...) body...)
```

To make things even more confusing, Common Lisp has provided for you an actual *macro* called **lamda**, which does exactly the same thing. Thus if you really want to (but it's not good style) you can write it as just:

```
(lambda (args...) body...)
```

```
[1]> (mapcar #'(lambda (x) (print (* x 2)))
             '(1 2 3 4 5 6))

2
4
6
8
10
12
(2 4 6 8 10 12)
[2]> (reduce #'(lambda (a b) (/ a (* b b)))
             '(2 3 4))    [(2 / 3^2) / 4^2]
1/72
[3]> (funcall #'(lambda (a b) (/ a (* b b))) 9 7)
9/49    [Not too useful this one, just an example...]
```

Lambda expressions are useful when you need to pass in a quick, short, temporary function. But there is another very powerful use of lambda expressions: making **closures**.

A closure is a function bundled together with its own *lexical scope*. Usually you can think of this as a closure being a function plus its own personal, private global variables.

When a function is built from a lambda expression, it is usually created in the context of some outer local variables. After the function is built, these variables are "trapped" with the lambda expression if anything in the lambda expression referred to them. Since the lambda expression is hanging on to these variables, they're not garbage collected when the local scope is exited. Instead they become private variables that only the function can see.

We can use this concept to make **function-building functions**. Consider:

```
(defun build-a-function (x)
       #'(lambda (y) (+ x y)))
```

...examine this function carefully. **build-a-function** takes a value *x* and then returns a function which adds that amount *x* to things!

```
[1]> (defun build-a-function (x)
       #'(lambda (y) (+ x y)))
BUILD-A-FUNCTION
[2]> (setf *+3* (build-a-function 3))
#<CLOSURE :LAMBDA (Y) (+ X Y)>
[3]> (funcall *+3* 9)
12
[4]> (funcall *+3* 2)
5
[5]> (setf *-6* (build-a-function -6))
#<CLOSURE :LAMBDA (Y) (+ X Y)>
[6]> (funcall *-6* 21)
15
[7] (funcall *-6* (funcall *+3* 38))
35
```

Closures are also common when we need to make a quick custom function based on information the user provided. Consider:

```
(defun add-to-list (val list-of-numbers)
  (mapcar #'(lambda (num) (+ val num))
          list-of-numbers))
```

```
[1]> (defun add-to-list (val list-of-numbers)
       (mapcar #'(lambda (num) (+ val num))
               list-of-numbers))
ADD-TO-LIST
[2]> (add-to-list 4 '(1 2 3 4 5))
(5 6 7 8 9)
[ Here's the more C++ way to do it... ]
```

...examine this function carefully as well. **add-to-list** takes a number *val* and a list of numbers. It then maps a custom function on the list of numbers. This custom function adds *val* to each one. The new list is then returned.

Notice that the lambda expression is converted into a function even though it refers to *val* **inside the lambda expression**.

Closures are examples of powerful things which **C++ simply cannot do.** Java gets there part-way. Java can do lambda expressions in the form of "anonymous classes". But it too cannot do real closures, though there are nasty hacks to work around the issue.

```
[3]> (defun icky-add-to-list (val list-of-numbers)
       (let (bag)
         (dolist (x list-of-numbers)
           (push (+ val x) bag))
         (reverse bag)))
ICKY-ADD-TO-LIST
[4]> (icky-add-to-list 4 '(1 2 3 4 5))
(5 6 7 8 9)
```

Closures also occur with **defun**. Imagine if **defun** were called *inside* a **let** statement:

```
(let ((seed 1234))
  (defun rand ()
    (setf seed (mod (* seed 16807) 2147483647))))
```

Here we defined a local variable called **seed**. Inside this local environment, we defined a function called **rand** which uses **seed**. When we leave the **let**, what happens to **seed**? Normally it would get garbage collected. But it can't here -- because **rand** is holding on to it. **seed** becomes a *private global variable* of the function **rand**. No one else can see it but **rand**.

You can use this for other interesting purposes. Imagine that you want to make a private bank account:

```
(let ((account 0))
  (defun deposit ($$$)
    (setf account (+ account $$$)))
  (defun withdraw ($$$)
    (setf account (- account $$$)))
  (defun amount ()
    account))
```

The functions **deposit**, **withdraw**, and **amount** share a common private variable called **account** that no one else can see.

This isn't much different from a Java or C++ object with a private instance variable and three methods. Where did you think object-oriented programming came from? You got it.

In fact, Lisp can be easily modified to do rather OOP built on top of closures. It comes with an OOP system, CLOS, as part of the language (though I think CLOS is too mammoth, so I usually make my own little OOP language in Lisp instead).

```
[1]> (let ((seed 1234))
  (defun rand ()
    (setf seed (mod (* seed 16807) 2147483647))))
RAND
[2]> (rand)
20739838
[3]> (rand)
682106452
[4]> (rand)
895431078
[5]> seed

*** - EVAL: variable SEED has no value
1. Break [6]> :a
[7]> (let ((account 0))
  (defun deposit ($$$)
    (setf account (+ account $$$)))
  (defun withdraw ($$$)
    (setf account (- account $$$)))
  (defun amount ()
    account))
AMOUNT
[8]> (deposit 42)
42
[9]> (withdraw 5)
37
[10]> (amount)
37
[11]> account

*** - EVAL: variable ACCOUNT has no value
```

Sequence Functions

Vectors (both simple and variable-length), lists, and strings are all **sequences**. Multidimensional arrays are *not* sequences.

A function which works with any kind of

```
[1]> (elt "hello world" 4)
#\o
[2]> (elt '(yo yo yo whats up?) 4)
UP?
[3]> (elt #(yo yo yo whats up?) 4)
```

sequence is a **sequence function** (duh). We've seen some examples of sequence functions before: **length**, **reverse**, **subseq**.

Another common sequence function is **elt**, of the form:

(elt *sequence index*)

elt returns element #*index* in the sequence. You can use **elt** inside **setf** to set the element (again, don't change elements in lists unless you know what you're doing. Strings and vectors are fine).

elt is an example of a general function: it works with a variety of data types, but as a result is slower than custom-made functions for each data type. For example, if you know your sequence is a string, **aref** is probably faster. If you know your sequence is a simple-vector, **svref** is much faster. Lists also have a faster function: **nth**.

```
UP?
```

copy-seq makes a duplicate copy of a sequence. It does not copy the elements (both sequences will point to the same elements).

concatenate concatenates copies of sequences together, producing a new sequence of a given type. The original sequences can be different types. **concatenate** looks like this:

(concatenate *new-sequence-type sequences...*)

new-sequence-type is a quoted symbol representing the *type* of the new sequence. For example, simple vectors use **'simple-vector** and lists use **'list** and strings use **'string**.

make-sequence builds a sequence of a given type and length. Like **elt**, it is a general function (it calls faster, more type-specific functions underneath). It looks like this:

(make-sequence *sequence-type length*)

make-sequence has a keyword argument **:initial-element** which can be used to set the initial element of the sequence.

concatenate and **make-sequence** show the first examples of **type symbols**. We'll talk about types more later.

```
[1]> (copy-seq "hello world")
"hello world"   [ the copied string ]
[2]> (concatenate 'string '(#\y #\o) #(#\space) "what's up?")
"yo what's up?"
[3]> (make-sequence 'string 4 :initial-element #\e)
"eeee"
```

A host of sequence-manipulative functions have very similar forms.

First off, most sequence-manipulative functions are either **destructive** or **non-destructive**. That is, either they modify or destroy the original sequence to achieve their goals (faster), or they make a copy of the sequence first. We'll show the non-destructive

```
[1]> (count #\l "hello world")
3
[ count the number of vowels in "hello world" ]
[2]> (count-if #'(lambda (i) (find i "aeiou")) "hello world")
3
[ count the number of non-alpha-chars in "hello world4" ]
[3]> (count-if-not #'alpha-char-p "hello world4")
2
[ remove the alpha chars from "hello world4" ]
[4]> (remove-if #'alpha-char-p "hello world4")
" 4"
```

versions first.

Second, a great many sequence functions have three versions, the function, the **-if** version, and the **-if-not** version. For example, the **count** function also has **count-if** and **count-if-not**. The forms look like this:

(count *object sequence keywords...*) counts the number of times *object* appears in *sequence*.

(count-if *test-predicate sequence keywords...*) counts the number of times in which *test-predicate* (a function pointer) returns true for elements in *sequence*.

(count-if-not *test-predicate sequence keywords...*) counts the number of times in which *test-predicate* (a function pointer) returns false (**nil**) for elements in *sequence*.

Third, many such functions take a *lot* of optional keyword arguments. Before testing to see if an element is the one we're looking for, these functions give you a chance to "extract" the relevant item out of the element with an optional function passed in with the keyword argument **:key**. You can tell the system to scan backwards with **:from-end t**. You can tell the system to only scan from a certain location to another location in the sequence with the keywords **:start** and **:end**. There are other keywords as well.

Other functions which follow this pattern include: **find** (returns the first element matching the pattern) else **nil**, **position** (returns the index of the first element matching the pattern) else **nil**, **remove** (removes all the elements matching the pattern from a *copy* of the sequence), and **substitute** (replaces all the elements matching the pattern with some other element). **substitute** has an additional argument indicating the item to replace stuff with, thus its three versions **substitute**, **substitute-if**, and **substitute-if-not** start like this:

(substitute[-if[-not]] *thing-to-replace-with rest-of-arguments-as-before...*)

```
[ find the first element < 4 in #(4 9 7 2 1 0 3) ]
[5]> (find-if #'(lambda (x) (< x 4)) #(4 9 7 2 1 0 3))
2
[ give the index of the first element < 4 in #(4 9 7 2 1 0 3) ]
[6]> (position-if #'(lambda (x) (< x 4)) #(4 9 7 2 1 0 3))
3
[ replace with NUMBER all the numbers in the list ]
[7]> (substitute-if 'number #'numberp '(a b 3 d "yo" 4.2 e))
(A B NUMBER D "yo" NUMBER E)
[ replace PI with 3.14159 for elements #4 through #9 ]
[8]> (substitute 3.14159 'pi
            '(pi a b pi c d e pi f pi pi g h pi)
            :start 4 :end 10)
(PI A B PI C D E 3.14159 F 3.14159 PI G H PI)
```

Another useful function, **search**, searches for the first index where one subsequence appears in another sequence. It takes the form:

(search *subsequence sequence keywords...*)

Keywords include **:key, :test, :test-not, :from-end, :start1, :end1, :start2, :end2**. Try them out and see what they do.

```
[1]> (search "wor" "hello world")
6
```

Many sequence functions have *destructive*

```
[1]> (setf *j* "hello world")
```

counterparts which are faster but **may** modify the original sequence rather than making a copy first and modifying the copy.

There are no promises with destructive functions: they may or may not modify the original. They may or may not modify the original into the form you're hoping for. The only guarantee they make is that the value they *return* will be what you're hoping for. Thus you should only use them on data that you don't care about any more.

The destructive form of **remove[-if[-not]]** is **delete[-if[-not]]**.

The destructive form of **substitute[-if[-not]]** is **nsubstitute[-if[-not]]**.

The destructive form of **reverse** is **nreverse**.

sort is destructive. Its basic form looks like this:

`(sort` *`sequence predicate`*`)`

```
"hello world"
[2]> (substitute #\Q #\l *j*)
"heQQo worQd"
[3]> *j*
"hello world"
[4]> (nsubstitute #\Q #\l *j*)
"heQQo worQd"
[5]> *j*
"heQQo worQd"
[6]> (sort '(4 3 5 2 3 1 3) #'>)
(5 4 3 3 3 2 1)
```

Functions With Variable Arguments

Now that we have enough functions to extract the elements of a list, we can talk about how to make a function which takes a variable number of arguments. The special term **&rest**, followed by an parameter name, can appear at the end of a parameter list in **defun**, musch as **&key** and **&optional** can appear.

If a function call provides any extra arguments beyond those defined in the parameter list, the additional arguments are all placed in a *list*, which the **&rest** parameter is set to. Otherwise it is set to **nil**.

Though it's possible to have rest-parameters along with keyword parameters and optional parameters in the same function, don't do it. Ick.

```
[1]> (defun mean (first-num &rest others)
[ others will be the list with remaining variable arguments ]
       "Returns the mean of a bunch of numbers.
There must be at least one number."
       (let ((nums (cons first-num others)))  ; nums is list of the numbers
          (/ (apply #'+ nums)
             (length nums))))

MEAN
[2]> (mean 10 2 3 4)
19/4
[3]> (mean 10)
10
[4]> (mean)

*** - EVAL/APPLY: too few arguments given to MEAN
[5]>
```

Lisp III

Yet more Lisp!

Legend

As before, the table cell to the right shows what you type, and the output, for this tutorial. Text shown in blue you are responsible for typing, with a Return at the end of the line. Text shown in black indicate stuff that is printed back to you. Text shown in red are remarks -- do not type them. If the cell is divided by a line, as is shown at right, then this indicates two different examples. You can go back to Tutorial 1 (QuickStart) or Tutorial 2.	This text is being printed out. You would type this text [This is a remark] Here is another example.

List Functions

Lisp's primary data type is the **list**. A list is a linked list elements. The linking structures are called **cons cells**. A cons cell is a structure with two fields: **car** and **cdr**. The **car** field points to the element the cons cell is holding. The **cdr** field points to the next cons cell, or to **nil** if the cons cell is at the end of the list. When you are storing a list, you are really storing a pointer to the first cons cell in the list. Thus **car** (**first**) returns the thing that cons cell is pointing to, and **cdr** (**rest**) returns the next cons cell (what the **cdr** is pointing to). Similarly, the **cons** function allocates a new cons cell, sets its **cdr** to the cons cell representing the original list, and sets its **car** to the element you're tacking onto the list. Thus the original list isn't modified at all! You've just made a new cons cell which reuses the list to "extend" it by one. **last** returns (as a list) the last *n* elements in the list. Really it just marches down the list and finds the appropriate cons and returns that to you. **last**'s argument is optional -- if it's not there, it returns (as a list) the last element in the list. **butlast** returns (as a list) a copy of everything *but* the last *n* elements in the list. **list** takes some *n* arguments and makes a list out of them. It differs from just quoting a list because the arguments are evaluated first (it's a function).	[1]> (last '(a b c d e)) (E) [2]> (last '(a b c d e) 3) (C D E) [3]> (butlast '(a b c d e)) (A B C D) [4]> (butlast '(a b c d e) 3) (A B) [5]> (list 1 2 (+ 3 2) "hello") (1 2 5 "hello") [6]> '(1 2 (+ 3 2) "hello") (1 2 (+ 3 2) "hello")
nth works on lists just like **elt**. You can use it in **setf**. For lists, it's a tiny bit faster than (the more general function) **elt**. Note that **nth**'s	[1]> (listp '(4 3 8)) T

arguments are not the same order as those for **elt**. This is historical.

listp is a predicate which returns true if its argument is a list.

atom is a predicate which returns true if its argument is an atom. Note that **nil** is both a list and an atom. It's the only thing which is both.

consp is a predicate which is true if its argument is a list but is *not* nil.

null is a predicate which returns true if its argument is **nil**.

If you think about it, the logical **not** function is identical to the **null** function.

There are a great many more list functions. See "conses" in the text.

```
[2]> (listp nil)
T
[3]> (consp '(4 3 8))
T
[4]> (consp nil)
NIL
[5]> (atom 'a)
T
[6]> (atom nil)
T
[7]> (null nil)
T
[8]> (not nil)
T
[9]> (nth 4 '(a b c d e))
E
```

There are a great many permuations of **cdr** and **car**.

caar is the same as `(car (car ... ))`

cdar is the same as `(cdr (car ... ))`

caadr is the same as `(car (car (cdr ... )))`

cddddr is the same as `(cdr (cdr (cdr (cdr ... ))))`

second through **tenth** return the second through the tenth elements of a list.

```
[1]> (caar '((a b c) ((d)) e f g h))
A
[2]> (cdar '((a b c) ((d)) e f g h))
(B C)
[3]> (caadr '((a b c) ((d)) e f g h))
(D)
[4]> (cddddr '((a b c) ((d)) e f g h))
(G H)
[5]> (fourth '((a b c) ((d)) e f g h))
F
```

The **cdr** field of a cons cell doesn't have to point to a list (or to **nil**). Technically, it can point to anything you like. For example, a single cons cell can point to 45 **car** and "hello" in its **cdr**. Such a cons cell is called a **dotted pair**, because its printed form is `(45 . "hello")`. Note the period.

You can construct long lists where the last item doesn't point to **nil** but instead is a dotted pair.

If you think about it, the dotted pair can only be at the *end* of a list.

Dotted pairs qualify as lists as far as **listp** is concerned.

```
[1]> (cons 45 "hello")
(45 . "hello")
[2]> (cons 'a (cons 'b (cons 45 "hello")))
(A B 45 . "hello")
[3]> (listp '(45 . "hello"))
T
```

Lists are constructed like beads of pearls. So far we've been careful not to damage them.

setf can be used to do evil things to a list.

You can use **setf** to modify a list. Since we construct lists which point to original lists, if we modify a list then it might modify other lists which pointed to it.

One particular danger is to use **setf** to modify cons cells to have circular references. For example, you could use **setf** to set the **cdr** of a cell point to the same cell.

Most Lisp systems are smart enough to detect circular references while printing a list to the screen. Some (like CLISP) are not! They'll go into an infinite loop trying to print such beasts. Try it out on osf1 for some fun as well.

```
[1]> (setf *x* '(a b c d e))
(A B C D E)
[2]> (setf *y* (rest *x*))
(B C D E)
[3]> (setf (rest *y*) '(1 2 3))
(1 2 3)
[4]> *y*
(B 1 2 3)
[5]> *x*
(A B 1 2 3)     [ hey, wait a minute! ]
[6]> (setf *x* '(a))
(A)
[7]> (setf (cdr *x*) *x*)
(A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 A A A A A A A A A A A A A A A A A A A A A A A A
 ...  [ ad naseum ]
```

There are a number of destructive versions of list functions. Just as in applying the destructive sequence functions to list, the same

```
[1]> (setf *x* '(a b c d e))
(A B C D E)
```

warning applies: destructive functions are faster and use much less memory, but because lists are strung together like beads of pearls, make sure you know what you're doing if you choose to use them! Here are two common ones:

nconc is the destructive version of **append**.

nbutlast is the destructive version of **butlast**.

```
[2]> (setf *y* '(1 2 3 4 5))
(1 2 3 4 5)
[3]> (nconc *x* *y*)
(A B C D E 1 2 3 4 5)
[4]> *x*
(A B C D E 1 2 3 4 5)   [ what the ... ]
[5]> (nbutlast 4 *x*)
(A B C D E 1)
[6]> *x*
(A B C D E 1)  [ it keeps modifying *x*! ]
```

Predicates and Types

Lisp has a number of predicates to compare equality. Here are some type-specific ones.

(= *num1 num2*) compares two numbers to see if they are equal. 2.0 and 2 are considered =. Also, -0 and 0 are =.

(char= *char1 char2*) compares two characters. (can you guess what **char>**, **char<=**, etc. do?)

(char-equal *char1 char2*) compares two characters in a case-insensitive way.

(string= *str1 str2*) compares two strings.

(string-equal *str1 str2*) compares two strings in a case-insensitive way.

There are also general equality predicates. These predicates vary in strength. Here are some loose descriptions.

(eq *obj1 obj2*) is true if *obj1* and *obj2* are *the exact same thing in memory*. Symbols and same-type numbers are the same thing: **(eq 'a 'a)** is true for example. But complex objects made separately aren't the same thing: **(eq '(1 2 3) '(1 2 3))** is false. Neither are integers and floats **eq** with one another: **(eq 0 0.0)** is false. **eq** is fast (it's a pointer comparison).

(eql *obj1 obj2*) is is like **eq** but also allows integers and floats to be the same (as in **(eq 0 0.0)** is true). **eql** is the default comparator for most stuff.

(equal *obj1 obj2*) says two objects are equal if they are **eql** or if they "look equal" and are lists, strings and pathnames, or bit-vectors.

(equalp *obj1 obj2*) says two objects are equal if they look equal. **equalp** compares nearly every kind of Lisp thing, including all sorts of numbers, symbols,

```
[1]> (eql '(a b) '(a b))
NIL
[2]> (equalp '(a b) '(a b))
T
[3]> (= 0.25 1/4)
T
[4]> (eq (setf *q* '(a b)) *q*)  [ remember the function rule ]
T
[5]> (string-equal "hello" "HelLo")
T
[6]> (= 1/5 .2)
NIL        [ what the ... ? ]
```

characters, arrays, strings, lists, hash tables, structures, files, you name it. **equalp** is the slowest comparator predicate, but you will generally find it to be the most useful.

Some numbers *should* be = but may not be due to numeric precision.

Lisp also has predicates to determine the **type** of objects. You've already seen some such predicates: **atom**, **null**, **listp**.

`(numberp` ***`obj`***`)` is true if *obj* is a number. There are a number of useful numerical predicates as well: **oddp** is true if the number is odd (see also **evenp**). **zerop** is true if the number is zero. **plusp** is true if the number is > 0. Etc.

characterp is true if *obj* is a character. There are a number of subpredicates, such as **alphanumericp** which is true if the character is a letter or a number.

symbolp is true if it's a symbol. **stringp** is true if it's a string. **arrayp** is true if it's an array. **vectorp** and **simple-vector-p** are...well you get the idea. There's a lot of this stuff.

```
[1]> (numberp 'a)
NIL
[2]> (stringp "hello")
T
```

Lisp has a general type-determination predicate called **typep**. It looks like this:

`(typep` ***`expression type`***`)`

A type is (usually but not always) a symbol representing the type (you have to quote it -- it's evaluated). Example types include **number, list, simple-vector, string,** etc.

Types are organized into a hierarchy: thus types can have subtypes (simple-vector is a subtype of vector, which is a subtype of array, for example). The root type is **t**. The **typep** function returns true if the expression has the type that as its base type or as a supertype.

Numeric types in particular have quite a lot of subtypes, such as **fixnum** (small integers), **bignum** (massive integers), **float**, **double-float**, **rational**, **real**, **complex**, etc.

```
[1]> (typep 'a 'symbol)
T
[2]> (typep "hello" 'string)
T
[3]> (typep 234098123423412341341234234234 'bignum)
T
[4]> (typep 234098123423412341341234234234 'rational)
T
[5]> (typep 1/9 'rational)
T
[6]> (typep 1/9 'list)
NIL
[7]> (typep 1/9 'foo)

*** - TYPEP: invalid type specification FOO
```

You can get the type of any expression with **`(type-of`** ***`expr`***`)`

```
[1]> (type-of 'float)
SYMBOL
[2]> (type-of 1/3)
RATIO
[3]> (type-of -2)
FIXNUM
[4]> (type-of "hello")
(SIMPLE-BASE-STRING 5) [ types can be lists starting with a symbol ]
[5]> (type-of (make-array '(3 3)))
(SIMPLE-ARRAY T (3 3))
[6]> (type-of nil)
NULL
```

Many objects may be *coerced* into another type, using the **coerce** function:

(coerce *expression type*)

Vectors and lists may be coerced into one another.

Strings may be coerced into other sequences, and lists or vectors of characters can be coerced into strings.

Integers may be coerced into floats. To convert a float or other rational into an integer, use one of the functions **floor**, **round**, **truncate** (round towards zero), or **ceiling**.

```
[1]> (coerce 4 'float)
4.0
[2]> (coerce "hello world" 'list)
(#\h #\e #\l #\l #\o #\Space #\w #\o #\r #\l #\d)
[3]> (coerce '(#\h #\e #\l #\l #\o #\Space #\w #\o #\r #\l #\d)
             'string)
"hello world"
[4]> (floor -4.3)
-5
[5]> (coerce '(a b c) 'simple-vector)
#(A B C)
[6]> (coerce '(a b c) 'string)

*** - SYSTEM::STORE: A does not fit into "", bad type
```

While we're on the subject of the four rounding functions (**floor**, **round**, **truncate**, **ceiling**), these are how you do integer division. Each function takes an optional argument, and divides the first argument by the second, then returns the appropriate rounding as an integer.

If you're used to C++ or Java's integer division, probably the most obvious choice is **truncate**.

Lisp functions can actually return more than one item. For example, integer division functions return both the divided value and the remainder. Both are printed to the screen. The primary return value (in this case, the divided value) is returned as normal. To access the "alternate" return value (in this case, the remainder), you need to use a macro such as **multiple-value-bind** or **multiple-value-list** (among others).

```
[1]> (floor 9 4)
2;    [ the primary return value ]
1     [ the alternative return value ]
[2]> (floor -9 4)
-3 ;
3
[3]> (truncate -9 4)
-2 ;
-1
[4]> (* 4 (truncate -9 4))
-8    [ 4 mulplied against the primary return value ]
[5]> (multiple-value-list (truncate -9 4))
(-2 -1)
[6]> (multiple-value-bind (x y) (truncate -9 4)
       (* x y))
2
```

Hash Tables

Hash tables are created with **make-hash-table**. You can hash with anything as a key. Hash tables by default use **eql** as a comparison predicate. This is almost always the wrong predicate to use: you usually would want to use **equal** or **equalp**. To do this for example, you type:

(make-hash-table :test #'equalp)

Elements are accessed with **gethash**. If the element doesn't exist, **nil** is returned. An alternative return value indicates whether or not the element exists

```
[1]> (setf *hash* (make-hash-table :test #'equalp))
#S(HASH-TABLE EQUALP)
[2]> (setf (gethash "hello" *hash*) '(a b c))
(A B C)
[3]> (setf (gethash 2 *hash*) 1/2)
1/2
[4]> (setf (gethash 2.0 *hash*) 9.2)  [ 2.0 is equalp to 2 ]
9.2
[5]> (gethash 2 *hash*)
9.2   [ because we're using equalp as a test ]
T     [ T because the slot exists in the hashtable ]
[6]> (setf (gethash #\a *hash*) nil)    [ store NIL as the value ]
NIL
[7]> (gethash #\b *hash*)
NIL;    [ No such key #\b in *hash* ]
NIL
[8]> (gethash #\a *hash*)
```

(returning T or NIL). If you stored **nil** as the value, then we have a problem! Instead of having to look up the alternate return value, you can supply an optional return value (instead of **nil**) to return if the slot really *is* empty.

(gethash *key hashtable &optional* return-if-empty)

Use **setf** to set hashed values.

(setf (gethash *key hashtable*) *value*)

Remove elements with **remhash**.

(remhash *key hashtable*)

Although it's not very efficient, you can map over a hashtable with **maphash**.

(maphash *function hashtable*)

function must take two arguments (the key and the value).

```
NIL;   [ uh... wait a minute... -- NIL is returned! ]
T
[9]> (gethash #\b *hash* 'my-empty-symbol)
MY-EMPTY-SYMBOL ;
NIL
[10]> (gethash #\a *hash* 'my-empty-symbol)
NIL;    [ that's better! ]
T
[11]> (maphash #'(lambda (key val) (print key)) *hash*)

2
"hello"
NIL
```

Printing and Reading

(tepri) prints a linefeed.

(print *obj*) of course prints a linefeed followed by *obj* (in a computer readable fashion). Unlike Java's **System.println("foo")** or C's **printf("foo\n")**, in Lisp it's traditional to print the newline *first*.

(prin1 *obj*) prints *obj* (in a computer readable fashion) -- no prior linefeed.

(princ *obj*) prints *obj* in a *human* readable fashion -- no prior linefeed. Strings are printed without "quotes", for example. Such printed elements aren't guaranteed to be readable back into the intepreter.

```
[1]> (progn (terpri) (terpri) (terpri) (print 'hello))



HELLO
HELLO
[2]> (progn (prin1 2) (prin1 '(a b c)) (prin1 "hello"))
2(A B C)"hello"
"hello"
[3]> (progn (princ 2) (princ '(a b c)) (princ "hello"))
2(A B C)hello
"hello"
```

(prin1-to-string *obj*) is like **prin1**, but the output is into a string.

(princ-to-string *obj*) is like **princ**, but the output is into a string.

```
[1]> (prin1-to-string 4.324)
"4.324"
[2]> (prin1-to-string "hello world")
"\"hello world\""
[3]> (princ-to-string "hello world")
"hello world"
[4]> (prin1-to-string '(a b "hello" c))
"(A B \"hello\" C)"
[5]> (princ-to-string '(a b "hello" c))
"(A B hello C)"
```

(read) reads in an expression from the command line.

read is a complete Lisp parser: it will read

```
[1]> (read)    [ Lisp waits for you to type an expression ]
'(a b c d)
(A B C D)
[2]> (read-from-string "'(a b c d)")
```

any expression.

(read-from-string *string*) reads in an expression from a string, and returns the expression plus an integer indicating at what point reading was completed.

(y-or-no-p) waits for the user to type in a yes or a no somehow, then returns it. The way the question is presented the user (graphical interface, printed on screen, etc.) is up to the Lisp system. **y-or-no-p** is a predicate.

```
'(A B C D) ;   [ Or equivalently (QUOTE (A B C D)) ]
10     [ Reading the expression finished before the tenth character ]
[3]> (y-or-n-p)   [ clisp waits for you to type y or n ]
TRUE      [ I tried to type in TRUE ]

Please answer with y or n : y   [ oh, okay! ]
T
```

format is a much more sophisticated printing facility. It is somewhat similar to C's **printf** command plus formating string. But **format**'s formatting string is much more capable. Generally, **format** looks like:

(format *print-to-where format-string obj1 obj2 ...*)

print-to-where can be **t** (print to the screen) or **nil** (print to a string).

Formatting sequences begin with a tilde (~). The simplest sequences include: **~a** (princ an element); **~%** (print a linefeed); **~s** (prin1 an element). Much more complex formatting includes very complex numerical printing, adding spaces and buffers, printing through lists, even printing in roman numerals! **format** has its own little programming language. It's astounding what **format** can do.

```
[1]> (format t "~%My name is ~a and my ID is ~a" "Sean" 1231)

My name is Sean and my ID is 1231
NIL
[2]> (format nil "~%~%~%~a~a~s    ~a" '(a b c)
         #(1 2 3) "yo" 'whatever)
"


(A B C)#(1 2 3)\"yo\"    WHATEVER"
[3]> (format t "~% ~a ~R ~:R ~@R ~:@R ~$ ~E" 4 4 4 4 4 4 4)

 4 four fourth IV IIII 4.00 4.0E+0    [ hee hee hee! ]
NIL
```

More Control Structures

(when *test expr1 expr2 ...*) evaluates the expressions (and returns the last) only if *test* is true, else it returns **nil**.

(unless *test expr1 expr2 ...*) evaluates the expressions (and returns the last) only if *test* is **nil**, else it returns **nil**.

(case *test-object case1 case2 ...*) goes through the cases one by one and returns the one which "matches" the *test-object*. A case looks like this:

(*obj expr1 expr2 ...*)

If *obj* (not evaluated, so you shouldn't quote it) is an object which is **eql** to *test-object*, or is a list in which *test-object* appears, then the case "matches" *test-object*. In this case, the expressions are evaluated left-to-right, and the last one is returned. *obj* can also be **t**, which matches anything. This is

```
[1]> (unless (y-or-n-p) (print "you picked no!")
                (print "good for you!"))
n

"you picked no!"
"good for you!"
"good for you!"
[2]> (defun type-discriminator (obj)
   "Prints out a guess at the type"
   (let ((typ (type-of obj)))
      (when (consp typ) (setf typ (first typ)))
      (case typ
         ((fixnum rational ratio complex real bignum)
            (print "a number perhaps?"))
         ((simple-vector vector string list)
            (print "some kind of sequence?"))
         (hash-table (print "hey, a hash table..."))
         (nil (print "it's nil!"))
         (t (print "beats me what this thing is.  It says:")
            (print (type-of obj))))))

TYPE-DISCRIMINATOR
[3]> (type-discriminator 42)

"a number perhaps?"
"a number perhaps?"
```

the "default" case.

If no case matches, then **case** returns nil.

case is a lot like the Java/C++ **switch** statement. There are other versions: **ecase**, **ccase**.

```
[4]> (type-discriminator "hello")

"beats me what this thing is.  It says:"
(SIMPLE-BASE-STRING 5)
(SIMPLE-BASE-STRING 5)
```

cond is a powerful generalization of **case**. It takes the form:

```
(cond (test1 expr expr ... )
      (test2 expr expr ... )
      (test3 expr expr ... )
      ... )
```

cond works like this. First, *test1* is evaluated. If this is true, the following expressions are evaluated and the last one is returned. If not, then *test2* is evaluated. If this is true, its following expressions are evaluated and the last one is true. And so on. If no test evaluates to true, then **nil** is returned.

```
[ Previously, type-discriminator didn't work for string.
  let's get it working right. ]
[2]> (defun type-discriminator (obj)
   "Prints out a guess at the type"
   (cond
      ((find-if #'(lambda (x) (typep obj x))
           '(fixnum rational ratio complex real bignum))
         (print "a number perhaps?"))
      ((find-if #'(lambda (x) (typep obj x))
           '(simple-vector vector string list))
         (print "some kind of sequence?"))
      ((typep obj 'hash-table) (print "hey, a hash table..."))
      ((typep obj null) (print "it's nil!"))
      (t (print "beats me what this thing is.  It says:")
         (print (type-of obj)))))

TYPE-DISCRIMINATOR
[3]> (type-discriminator "hello")

"some kind of sequence?"
"some kind of sequence?"
```

do is a general iterator. It takes the form:

```
(do (initial-variable-declarations)
      (test res-expr1 res-expr2 ... )
      expr1
      expr2
      ... )
```

do works like this. First, local variables are declared in a way somwhat similarly to **let** (we'll get to that). Then *test* is evaluated. If it is true, then the *res-expr*'s are evaluated and the last one is returned (if there are none, then **nil** is returned).

If *test* returned false, then *expr*'s in the body are evaluated. Then **do** iterates again, starting with trying *test* again. And so on.

A variable declaration is either a variable name (a symbol), just as in **let**, or it is a list of the form **(*var optional-init optional-update*)** The *optional-init* expression initializes the variable (else it's **nil**). The *optional-update* expression specifies the new value of *var* each iteration. *optional-update* is evaluated in the context of the variables of the previous iteration.

```
[ generate some random numbers ]
[2]> (defun generate (num)
       (do ((y 0 (1+ y))
            (x 234567 (mod (* x 16807) 2147483647)))
           ((>= y num) "the end!")
           (print x)))
GENERATE
[3]> (generate 20)

234567
1794883922
911287645
158079111
398347238
1315501367
1287329304
245868803
558435193
1116751361
233049547
2001047948
2018950016
103812665
1022739291
720153249
397821451
1068533846
1590093508
1415085688
"the end!"
```

loop is a very powerful, complex iteration macro which can do nearly anything. Literally. It has its own language built into it. **loop** is one of the few things in Lisp more complex than **format**.

loop has an idiosyncratic syntax that is very un-lisp-like. It is also so complex that few people understand it, and it is not recommended for use. We will not discuss **loop** except to mention that its very simplest form: **(loop *expressions* ...)** makes a very nice infinite loop.

```
[2]> (loop (print 'hello) (print 'yo))
HELLO
YO
HELLO
YO
HELLO
YO
HELLO
YO
 [ ... ad nauseum until you press Control-C ]
```

A **block** is a sequence of expressions. Blocks

appear in lots of control structures, such as **let**, all iterators (**do**, **dotimes**, **dolist**, **loop**, etc.), many conditional statements (**cond**, **case**, **when**, etc.), **progn**, etc.

Blocks have **labels** (names). In control structures, the implicit blocks are all named **nil**.

Functions created with **defun** have an implicit block whose label is the same name as the function. Functions created with **lambda** have an implicit block whose label is **nil**.

(return-from *label optional-value*) will exit prematurely from a block whose label is *label* (not evaluated -- don't quote it). This is somewhat like Java/C++'s **break** statement. The return value of the block is *optional-value* (or **nil** if no value provided).

Because so many blocks are named **nil**, the simpler **(return *optional-value*)** is the same thing as **(return-from nil *optional-value*)**

Use **return** and **return-from** sparingly. They should be rare.

```
[1]> (dotimes (x 100)
       (print x)
       (if (> x 10) (return 'hello)))

0
1
2
3
4
5
6
7
8
9
10
11
HELLO
[2]> (defun differents (list &key (test #'eql))
       "Returns the first different pair in list"
       (dolist (x list)
         (dolist (y list)
           (unless (funcall test x y)
             (return-from differents (list x y))))))
DIFFERENTS
[3]> (differents '(a a a b c d))
(A B)
[4]> (differents '(a a a a a a))
NIL
```

Another way to escape is with **catch** and **throw**. **catch** looks like this:

(catch *catch-symbol expressions ...*)

throw looks like:

(throw *catch-symbol return-value*)

Normally, **catch** works just like **progn**. But if there is a **throw** statement inside the **catch** whose *catch-symbol* matches the **catch**'s, then we prematurely drop out of the **catch** and the **catch** returns the return value of the **throw**.

This works even if the **throw** appears in a subfunction called inside the **catch**.

In C++ such a thing is done with **longjump**. In Java such a thing is done with an exception.

```
[ another way to do the differents function ]
[2]> (defun differents (list &key (test #'eql))
       "Returns the first different pair in list"
       (catch 'my-return-value
         (dolist (x list)
           (dolist (y list)
             (unless (funcall test x y)
               (throw 'my-return-value (list x y)))))))
DIFFERENTS
[3]> (differents '(a a a b c d))
(A B)
[4]> (differents '(a a a a a a))
NIL
```

Writing Lisp in Lisp

Lisp has a built-in interpreter. It is called **eval**, and looks like this:

(eval *data*)

eval takes *data* and submits it to the Lisp interpreter to be executed.

The data submitted to the interpeter is not evaluated in the context of any current local variables.

eval is powerful. You can assemble lists and then have them executed as code. Thus **eval** allows you to make lisp programs which generate lisp code on-the-fly. C++ and Java can only do this in truly evil ways (like writing machine code

```
[1]> (list '+ 4 7 9)
(+ 4 7 9)
[2]> (eval (list '+ 4 7 9))
20
```

to an array, then casting it into a function, yikes!).	

Lisp has an interpeter **eval**, a full-featured printer **print**, and a full-featured parser **read**. Using these tools, we can create our own Lisp command line!	`[1]> (loop (format t "~%my-lisp --> ")`
	`(print (eval (read))))`
	
	`my-lisp --> (dotimes (x 10) (print 'hi))`
	
	`HI`
	`HI`
	`HI`
	`HI`
	`HI`
	`HI`
	`HI`
	`HI`
	`HI`
	`NIL`
	`my-lisp -->`

More Debugging

`(break)` signals an error, just as if the user pressed Control-C.
 	
You can continue from a break.
	`[1]> (defun foo (x)`
	`(print (+ x 3))`
	`(break)`
	`(print (+ x 4)))`
	
	`FOO`
	`[2]> (foo 7)`
	
	`10`
	`** - Continuable Error`
	`Break`
	`If you continue (by typing 'continue'): Return from BREAK loop`
	`2. Break [4]> continue  [in clisp, anyway]`
	
	`11`
	`11`

`(trace` ***`function-symbol`*****`)`** turns on tracing of a function. *function-symbol* is not evaluated (don't quote it or sharp-quote it).
 	
When a trace function is entered, the function and its arguments are printed to the screen. When the trace function exits, its return value is printed to the screen.
 	
You can trace multiple functions at the same time.
 	
You turn off tracing of a function with **`(untrace`** ***`function-symbol`*****`)`**
	`[1]> (defun factorial (n)`
	`(if (<= n 0)`
	`1`
	`(* n (factorial (- n 1)))))`
	`FACTORIAL`
	`[2]> (trace factorial)`
	`(FACTORIAL)`
	`[3]> (factorial 15)`
	
	`1. Trace: (FACTORIAL '15)`
	`2. Trace: (FACTORIAL '14)`
	`3. Trace: (FACTORIAL '13)`
	`4. Trace: (FACTORIAL '12)`
	`5. Trace: (FACTORIAL '11)`
	`6. Trace: (FACTORIAL '10)`
	`7. Trace: (FACTORIAL '9)`
	`8. Trace: (FACTORIAL '8)`
	`9. Trace: (FACTORIAL '7)`
	`10. Trace: (FACTORIAL '6)`
	`11. Trace: (FACTORIAL '5)`
	`12. Trace: (FACTORIAL '4)`
	`13. Trace: (FACTORIAL '3)`
	`14. Trace: (FACTORIAL '2)`
	`15. Trace: (FACTORIAL '1)`
	`16. Trace: (FACTORIAL '0)`
	`16. Trace: FACTORIAL ==> 1`
	`15. Trace: FACTORIAL ==> 1`
	`14. Trace: FACTORIAL ==> 2`
	`13. Trace: FACTORIAL ==> 6`
	`12. Trace: FACTORIAL ==> 24`
	`11. Trace: FACTORIAL ==> 120`
	`10. Trace: FACTORIAL ==> 720`

```
9. Trace: FACTORIAL ==> 5040
8. Trace: FACTORIAL ==> 40320
7. Trace: FACTORIAL ==> 362880
6. Trace: FACTORIAL ==> 3628800
5. Trace: FACTORIAL ==> 39916800
4. Trace: FACTORIAL ==> 479001600
3. Trace: FACTORIAL ==> 6227020800
2. Trace: FACTORIAL ==> 87178291200
1. Trace: FACTORIAL ==> 1307674368000
1307674368000
[4]> (untrace factorial)
(FACTORIAL)
[5]>  (factorial 15)
1307674368000
```

You can step through an expression's evaluation, just as in a debugger, using **`(step`** ***`expression`*****`)`**. The features available within the **step** environment are implementation-dependent.

In clisp, the **step** function lets you interactively type, among other things, **:s** (to step into an expression), **:n** (to complete the evaluation of the expression and step out), and **:a** (to abort stepping)

```
[1]> (defun factorial (n)
       (if (<= n 0)
         1
         (* n (factorial (- n 1)))))
FACTORIAL
[2]> (step (factorial 4))
(step (factorial 4))
step 1 --> (FACTORIAL 4)
Step 1 [26]> :s
step 2 --> 4
Step 2 [27]> :s

step 2 ==> value: 4
step 2 --> (IF (<= N 0) 1 (* N (FACTORIAL #)))
Step 2 [28]> :s
step 3 --> (<= N 0)
Step 3 [29]> :n

step 3 ==> value: NIL
step 3 --> (* N (FACTORIAL (- N 1)))
Step 3 [30]> :s
step 4 --> N
Step 4 [31]> :s

step 4 ==> value: 4
step 4 --> (FACTORIAL (- N 1))
Step 4 [32]> :s
step 5 --> (- N 1)
Step 5 [33]> :n

step 5 ==> value: 3
step 5 --> (IF (<= N 0) 1 (* N (FACTORIAL #)))
Step 5 [34]> :n

step 5 ==> value: 6
step 4 ==> value: 6
step 3 ==> value: 24
step 2 ==> value: 24
step 1 ==> value: 24
24
```

The **apropos** function can be used to find all the defined symbols in the system which match a given string. Ordinarily, **apropos** will return *everything*, including private system symbols. That's not what you'd want. But the following will do the trick:

`(apropos` ***`matching-string`*** **`'cl-user)`**

NOTE: A bug in CMUCL (CMU Common Lisp) means that it doesn't know to join the 'cl and 'cl-user packages together into just 'cl-user when responding to **apropos**. So if you're using CMUCL, you need to

```
[ in clisp  ]
[1]> (apropos "compile" 'cl-user)
*COMPILE-FILE-PATHNAME*                 variable
*COMPILE-FILE-TRUENAME*                 variable
*COMPILE-PRINT*                         variable
*COMPILE-VERBOSE*                       variable
*COMPILE-WARNINGS*                      variable
*COMPILED-FILE-TYPES*                   variable
COMPILE                                 function
COMPILE-FILE                            function
COMPILE-FILE-PATHNAME                   function
COMPILED-FUNCTION                       type
COMPILED-FUNCTION-P                     function
COMPILER-LET                            special operator
COMPILER-MACRO
COMPILER-MACRO-FUNCTION                 function
DEFINE-COMPILER-MACRO                   macro
UNCOMPILE                               function
```

```
[ in LispWorks ]
```

do something like:

```
(defun my-apropos (string)
   (apropos string 'cl)
   (apropos string 'cl-user))
```

...then you can call **`(my-apropos "compile")`** and you'll get the right stuff. Don't bother with this hack on CLISP, LispWorks, or other correctly-working Lisps with regard to **apropos**.

```
[1]> (apropos "compile" 'cl-user)
COMPILER
COMPILED-FUNCTION
*COMPILE-FILE-PATHNAME*, value: NIL
COMPILE-FILE (defined)
COMPILER-MACRO
COMPILE (defined)
COMPILED-FUNCTION-P (defined)
*COMPILE-FILE-TRUENAME*, value: NIL
COMPILE-FILE-PATHNAME (defined)
COMPILER-MACRO-FUNCTION (defined)
*COMPILE-PRINT*, value: 1
*COMPILE-VERBOSE*, value: T
DEFINE-COMPILER-MACRO (defined macro)
COMPILER-MACROEXPAND (defined)
COMPILE-FILE-IF-NEEDED (defined)
*COMPILER-BREAK-ON-ERROR*, value: NIL
COMPILER-MACROEXPAND-1 (defined)
*STEP-COMPILED*, value: NIL
EXIT-COMPILE-FILE (defined macro)
COMPILE-SYSTEM (defined)
COMPILER-LET (defined)
```

You can disassemble a function with **`(disassemble` *`function-pointer`*`)`**

You can use **disassemble** to assess the quality of your function in terms of machine code instructions. Compiled and interpreted functions may or may not appear to disassemble differently. Disassembly is implementation-dependent and processor-dependent.

```
[ in clisp  ]
[1]> (defun factorial (n)
          (if (<= n 0)
            1
            (* n (factorial (- n 1)))))
FACTORIAL
[3]> (disassemble 'factorial)

Disassembly of function FACTORIAL
(CONST 0) = 0
(CONST 1) = 1
1 required arguments
0 optional arguments
No rest parameter
No keyword parameters
0     L0
0     (LOAD&PUSH 1)
1     (CONST&PUSH 0)                        ; 0
2     (CALLSR&JMPIF 1 50 L16)               ; <=
6     (LOAD&PUSH 1)
7     (LOAD&DEC&PUSH 2)
9     (JSR&PUSH L0)
11    (CALLSR 2 56)                         ; *
14    (SKIP&RET 2)
16    L16
16    (CONST 1)                             ; 1
17    (SKIP&RET 2)
#<COMPILED-CLOSURE FACTORIAL>     [ dunno why clisp says it's compiled ]
```

```
[ in Lispworks ]

CL-USER 39 >  (defun factorial (n)
          (if (<= n 0)
            1
            (* n (factorial (- n 1)))))
FACTORIAL

CL-USER 40 > (disassemble #'factorial)
#x300F9158: #xA0E20692  ldl tmp3,nil,1682
#x300F915C: #x40FE0527  subq tmp3,sp,tmp3
#x300F9160: #xFCE00039  bgt tmp3,#x300F9248
#x300F9164: #x402035A6  cmpeq arg/mv,1,tmp2
#x300F9168: #xE4C00037  beq tmp2,#x300F9248
#x300F916C: #x23DEFFF0  lda sp,sp,-16
#x300F9170: #xB1FE0000  stl fp,sp,0
#x300F9174: #x43C0100F  addl sp,0,fp
#x300F9178: #xB09E0004  stl constants,sp,4
#x300F917C: #xA0830006  ldl constants,func,6
#x300F9180: #xB19E0008  stl r12,sp,8
#x300F9184: #x4610040C  bis arg0,arg0,r12
#x300F9188: #xB35E000C  stl ra,sp,12
#x300F918C: #xA0C4001D  ldl tmp2,constants,29 ;; "call-count"
#x300F9190: #x45807007  and r12,3,tmp3
#x300F9194: #x40C09006  addl tmp2,4,tmp2
```

```
#x300F9198: #xB0C4001D  stl tmp2,constants,29 ;; "call-count"
#x300F919C: #xF4E0000C  bne tmp3,#x300F91D0
#x300F91A0: #xFD800011  bgt r12,#x300F91E8
#x300F91A4: #x47FF041F  bis zero,zero,zero
#x300F91A8: #x47E03401  bis zero,1,arg/mv
#x300F91AC: #x47E09400  bis zero,4,result
#x300F91B0: #x45EF041E  bis fp,fp,sp
#x300F91B4: #xA35E000C  ldl ra,sp,12
#x300F91B8: #xA19E0008  ldl r12,sp,8
#x300F91BC: #xA09E0004  ldl constants,sp,4
#x300F91C0: #xA1FE0000  ldl fp,sp,0
#x300F91C4: #x23DE0010  lda sp,sp,16
#x300F91C8: #x6BFA8000  ret zero,(ra)
#x300F91CC: #x47FF041F  bis zero,zero,zero
#x300F91D0: #x20A20B26  lda tmp1,nil,2854
#x300F91D4: #x47FF0411  bis zero,zero,arg1
#x300F91D8: #x458C0410  bis r12,r12,arg0
#x300F91DC: #x6B454000  jsr ra,(tmp1)
#x300F91E0: #x400205A5  cmpeq result,nil,tmp1
#x300F91E4: #xE4BFFFF0  beq tmp1,#x300F91A8
#x300F91E8: #x45807007  and r12,3,tmp3
#x300F91EC: #xF4E00018  bne tmp3,#x300F9250
#x300F91F0: #x41809130  subl r12,4,arg0
#x300F91F4: #x420C09A6  cmplt arg0,r12,tmp2
#x300F91F8: #xE4C00015  beq tmp2,#x300F9250
#x300F91FC: #x47FF041F  bis zero,zero,zero
#x300F9200: #xA064002D  ldl func,constants,45 ;; FACTORIAL
#x300F9204: #x47E03401  bis zero,1,arg/mv
#x300F9208: #xA0A30002  ldl tmp1,func,2
#x300F920C: #x40A0B405  addq tmp1,5,tmp1
#x300F9210: #x6B454000  jsr ra,(tmp1)
#x300F9214: #x44000411  bis result,result,arg1
#x300F9218: #x4591041D  bis r12,arg1,r29
#x300F921C: #x47A07007  and r29,3,tmp3
#x300F9220: #xF4E00011  bne tmp3,#x300F9268
#x300F9224: #x4980579D  sra r12,2,r29
#x300F9228: #x4FB10400  mulq r29,arg1,result
#x300F922C: #x48041786  sra result,32,tmp2
#x300F9230: #x401F0000  addl result,zero,result
#x300F9234: #x4803F787  sra result,31,tmp3
#x300F9238: #x40E605A7  cmpeq tmp3,tmp2,tmp3
#x300F923C: #xE4E0000A  beq tmp3,#x300F9268
#x300F9240: #x47E03401  bis zero,1,arg/mv
#x300F9244: #xC3FFFFDA  br zero,#x300F91B0
#x300F9248: #x20A20EF6  lda tmp1,nil,3830
#x300F924C: #x6BE50000  jmp zero,(tmp1)
#x300F9250: #x20A20C8E  lda tmp1,nil,3214
#x300F9254: #x47E09411  bis zero,4,arg1
#x300F9258: #x458C0410  bis r12,r12,arg0
#x300F925C: #x6B454000  jsr ra,(tmp1)
#x300F9260: #x44000410  bis result,result,arg0
#x300F9264: #xC3FFFFE6  br zero,#x300F9200
#x300F9268: #x458C0410  bis r12,r12,arg0
#x300F926C: #x45EF041E  bis fp,fp,sp
#x300F9270: #x20A20CD6  lda tmp1,nil,3286
#x300F9274: #xA19E0008  ldl r12,sp,8
#x300F9278: #xA09E0004  ldl constants,sp,4
#x300F927C: #xA1FE0000  ldl fp,sp,0
#x300F9280: #xA35E000C  ldl ra,sp,12
#x300F9284: #x23DE0010  lda sp,sp,16
#x300F9288: #x6BE50000  jmp zero,(tmp1)
#x300F928C: #x47FF041F  bis zero,zero,zero
78
NIL
```

```
 [In CMU Common Lisp (CMUCL), just for the heck of it!]
*  (disassemble #'factorial)
Compiling LAMBDA (N):
Compiling Top-Level Form:
40134198:       .ENTRY "LAMBDA (N)"(n)       ; (FUNCTION (T) NUMBER)
     1B0:       ADD         -18, %CODE
     1B4:       ADD         %CFP, 32, %CSP

     1B8:       CMP         %NARGS, 4        ; %NARGS = #:G0
     1BC:       BPNE,PN     %ICC, L2
     1C0:       NOP
     1C4:       ST          %A0, [%CFP+12]   ; %A0 = #:G1
     1C8:       ST          %OCFP, [%CFP]
     1CC:       ST          %LRA, [%CFP+4]   ; No-arg-parsing entry point
     1D0:       LDUW        [%CFP+12], %A0
     1D4:       ADD         %ZERO, 0, %A1
     1D8:       ADD         %CODE, 104, %LRA
```

```
     1DC:       SETHI      %hi(#x10001000), %NL0
     1E0:       J          %NL0+944          ; #x100013B0: GENERIC->
     1E4:       NOP
     1E8:       .LRA
     1EC:       MOV        %OCFP, %CSP
     1F0:       NOP
     1F4:       ADD        -104, %CODE
     1F8:       CMP        %A0, %NULL
     1FC:       BPNE       %ICC, L1
     200:       NOP

     204:       ADD        %ZERO, 4, %A0
     208: L0:   LDUW       [%CFP], %NL0
     20C:       LDUW       [%CFP+4], %A1

;;; [5] (<= N 0)

     210:       MOV        %CFP, %CSP
     214:       MOV        %NL0, %CFP
     218:       J          %A1+5
     21C:       MOV        %A1, %CODE
     220: L1:   LDUW       [%CFP+12], %A0
     224:       ADD        %ZERO, 4, %A1
     228:       ADD        %CODE, 184, %LRA
     22C:       SETHI      %hi(#x10000000), %NL0
     230:       J          %NL0+740          ; #x100002E4: GENERIC--
     234:       NOP

;;; [4] (IF (<= N 0) 1 (* N (FACTORIAL #)))

     238:       .LRA

     23C:       MOV        %OCFP, %CSP
     240:       NOP
     244:       ADD        -184, %CODE
     248:       LDUW       [%CODE+13], %CNAME ; #
     24C:       ADD        %ZERO, 4, %NARGS
     250:       LDUW       [%CNAME+5], %A1

;;; [6] (* N (FACTORIAL (- N 1)))

     254:       ADD        %CODE, 232, %LRA
     258:       MOV        %CFP, %OCFP
     25C:       MOV        %CSP, %CFP

;;; [8] (- N 1)

     260:       J          %A1+23
     264:       MOV        %A1, %CODE
     268:       .LRA
     26C:       MOV        %OCFP, %CSP
     270:       NOP
     274:       ADD        -232, %CODE
     278:       MOV        %A0, %A1
     27C:       LDUW       [%CFP+12], %A0
     280:       ADD        %CODE, 272, %LRA
     284:       SETHI      %hi(#x10000000), %NL0
     288:       J          %NL0+856          ; #x10000358: GENERIC-*
     28C:       NOP
     290:       .LRA

;;; [7] (FACTORIAL (- N 1))

     294:       MOV        %OCFP, %CSP
     298:       NOP
     29C:       ADD        -272, %CODE
     2A0:       BP         %ICC, L0
     2A4:       NOP
     2A8: L2:   ILLTRAP    10                ; Error trap
     2AC:       BYTE       #x04
     2AD:       BYTE       #x19              ; INVALID-ARGUMENT-COUNT-ERROR
     2AE:       BYTE       #xFE, #xED, #x01  ; NARGS
     2B1:       .ALIGN     4
```