

# *How to Design Programs Languages*

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The languages documented in this manual are provided by DrScheme to be used with the *How to Design Programs* book.

# Contents

<b>1</b>	<b>Beginning Student</b>	<b>5</b>
1.1	define . . . . .	10
1.2	define-struct . . . . .	11
1.3	Function Calls . . . . .	12
1.4	Primitive Calls . . . . .	12
1.5	cond . . . . .	12
1.6	if . . . . .	13
1.7	and . . . . .	13
1.8	or . . . . .	13
1.9	Test Cases . . . . .	14
1.10	empty . . . . .	14
1.11	Identifiers . . . . .	14
1.12	Symbols . . . . .	14
1.13	true and false . . . . .	15
1.14	require . . . . .	15
1.15	Primitive Operations . . . . .	16
<b>2</b>	<b>Beginning Student with List Abbreviations</b>	<b>35</b>
2.1	Quote . . . . .	41
2.2	Quasiquote . . . . .	41
2.3	Primitive Operations . . . . .	42
2.4	Unchanged Forms . . . . .	61
<b>3</b>	<b>Intermediate Student</b>	<b>63</b>
3.1	define . . . . .	70

3.2	<code>define-struct</code> . . . . .	70
3.3	<code>local</code> . . . . .	70
3.4	<code>letrec</code> , <code>let</code> , and <code>let*</code> . . . . .	71
3.5	Function Calls . . . . .	71
3.6	<code>time</code> . . . . .	71
3.7	Identifiers . . . . .	72
3.8	Primitive Operations . . . . .	72
3.9	Unchanged Forms . . . . .	93
<b>4</b>	<b>Intermediate Student with Lambda</b>	<b>94</b>
4.1	<code>define</code> . . . . .	101
4.2	<code>lambda</code> . . . . .	101
4.3	Function Calls . . . . .	101
4.4	Primitive Operation Names . . . . .	101
4.5	Unchanged Forms . . . . .	122
<b>5</b>	<b>Advanced Student</b>	<b>124</b>
5.1	<code>define</code> . . . . .	131
5.2	<code>define-struct</code> . . . . .	132
5.3	<code>lambda</code> . . . . .	132
5.4	Function Calls . . . . .	132
5.5	<code>begin</code> . . . . .	133
5.6	<code>begin0</code> . . . . .	133
5.7	<code>set!</code> . . . . .	133
5.8	<code>delay</code> . . . . .	133
5.9	<code>shared</code> . . . . .	133

5.10 let . . . . .	134
5.11 recur . . . . .	134
5.12 case . . . . .	134
5.13 when and unless . . . . .	135
5.14 Primitive Operations . . . . .	135
5.15 Unchanged Forms . . . . .	158
<b>Index</b>	<b>160</b>

# 1 Beginning Student

```
program = def-or-expr ...

def-or-expr = definition
            | expr
            | test-case
            | library-require

definition = (define (id id id ...) expr)
            | (define id expr)
            | (define id (lambda (id id ...) expr))
            | (define-struct id (id ...))

expr = (id expr expr ...) ; function call
      | (prim-op expr ...) ; primitive operation call
      | (cond [expr expr] ... [expr expr])
      | (cond [expr expr] ... [else expr])
      | (if expr expr expr)
      | (and expr expr expr ...)
      | (or expr expr expr ...)
      | empty
      | id
      | id ; identifier
      | 'id ; symbol
      | number
      | true
      | false
      | string
      | character

test-case = (check-expect expr expr)
          | (check-within expr expr expr)
          | (check-error expr expr)

library-require = (require string)
                | (require (lib string string ...))
                | (require (planet string package))

package = (string string number number)
```

An *id* is a sequence of characters not including a space or one of the following:

```
" , ' ( ) [ ] { } | ; #
```

A *number* is a number such as 123, 3/2, or 5.5.

A *string* is enclosed by a pair of `"`. Unlike symbols, strings may be split into characters and manipulated by a variety of primitive functions. For example, `"abcdef"`, `"This is a string"`, and `"This is a string with \" inside"` are all strings.

A *character* begins with `#\` and has the name of the character. For example, `#\a`, `#\b`, and `#\space` are characters.

A *prim-op* is one of:

**Numbers: Integers, Rationals, Reals, Complex, Exacts, Inexacts**

```
* : (num num num ... -> num)
+ : (num num num ... -> num)
- : (num num ... -> num)
/ : (num num num ... -> num)
< : (real real real ... -> boolean)
<= : (real real real ... -> boolean)
= : (num num num ... -> boolean)
> : (real real real ... -> boolean)
>= : (real real ... -> boolean)
abs : (real -> real)
acos : (num -> num)
add1 : (number -> number)
angle : (num -> real)
asin : (num -> num)
atan : (num -> num)
ceiling : (real -> int)
complex? : (any -> boolean)
conjugate : (num -> num)
cos : (num -> num)
cosh : (num -> num)
current-seconds : (-> int)
denominator : (rat -> int)
e : real
even? : (integer -> boolean)
exact->inexact : (num -> num)
exact? : (num -> boolean)
exp : (num -> num)
expt : (num num -> num)
floor : (real -> int)
gcd : (int int ... -> int)
imag-part : (num -> real)
inexact->exact : (num -> num)
inexact? : (num -> boolean)
integer->char : (int -> char)
integer? : (any -> boolean)
lcm : (int int ... -> int)
log : (num -> num)
```

```

magnitude : (num -> real)
make-polar : (real real -> num)
max : (real real ... -> real)
min : (real real ... -> real)
modulo : (int int -> int)
negative? : (number -> boolean)
number->string : (num -> string)
number? : (any -> boolean)
numerator : (rat -> int)
odd? : (integer -> boolean)
pi : real
positive? : (number -> boolean)
quotient : (int int -> int)
random : (int -> int)
rational? : (any -> boolean)
real-part : (num -> real)
real? : (any -> boolean)
remainder : (int int -> int)
round : (real -> int)
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
sin : (num -> num)
sinh : (num -> num)
sqr : (num -> num)
sqrt : (num -> num)
sub1 : (number -> number)
tan : (num -> num)
zero? : (number -> boolean)

```

### Booleans

```

boolean=? : (boolean boolean -> boolean)
boolean? : (any -> boolean)
false? : (any -> boolean)
not : (boolean -> boolean)

```

### Symbols

```

symbol->string : (symbol -> string)
symbol=? : (symbol symbol -> boolean)
symbol? : (any -> boolean)

```

### Lists

```

append : ((listof any)
          (listof any)
          (listof any)
          ...
          ->
          (listof any))

```

```

assq : (X
        (listof (cons X Y))
        ->
        (union false (cons X Y)))
caaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         W)
caadr : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         Z)
caddr : ((listof Y) -> Y)
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
cadr : ((cons Z (cons Y (listof X))) -> Y)
car : ((cons Y (listof X)) -> Y)
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
         ->
         (listof Y))
cdar : ((cons (cons Z (listof Y)) (listof X))
         ->
         (listof Y))
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         (listof Y))
cddr : ((cons W (cons Z (cons Y (listof X))))
         ->
         (listof X))
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
cdr : ((cons Y (listof X)) -> (listof X))
cons : (X (listof X) -> (listof X))
cons? : (any -> boolean)
eighth : ((listof Y) -> Y)
empty? : (any -> boolean)
fifth : ((listof Y) -> Y)

```



```

first : ((cons Y (listof X)) -> Y)
fourth : ((listof Y) -> Y)
length : ((listof any) -> number)
list : (any ... -> (listof any))
list* : (any ... (listof any) -> (listof any))
list-ref : ((listof X) natural-number -> X)
member : (any (listof any) -> boolean)
memq : (any (listof any) -> (union false list))
memv : (any (listof any) -> (union false list))
null : empty
null? : (any -> boolean)
pair? : (any -> boolean)
rest : ((cons Y (listof X)) -> (listof X))
reverse : ((listof any) -> list)
second : ((cons Z (cons Y (listof X))) -> Y)
seventh : ((listof Y) -> Y)
sixth : ((listof Y) -> Y)
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)

```

### Posns

```

make-posn : (number number -> posn)
posn-x : (posn -> number)
posn-y : (posn -> number)
posn? : (anything -> boolean)

```

### Characters

```

char->integer : (char -> integer)
char-alphabetic? : (char -> boolean)
char-ci<=? : (char char char ... -> boolean)
char-ci<? : (char char char ... -> boolean)
char-ci=? : (char char char ... -> boolean)
char-ci>=? : (char char char ... -> boolean)
char-ci>? : (char char char ... -> boolean)
char-downcase : (char -> char)
char-lower-case? : (char -> boolean)
char-numeric? : (char -> boolean)
char-upcase : (char -> char)
char-upper-case? : (char -> boolean)
char-whitespace? : (char -> boolean)
char<=? : (char char char ... -> boolean)
char<? : (char char char ... -> boolean)
char=? : (char char char ... -> boolean)
char>=? : (char char char ... -> boolean)
char>? : (char char char ... -> boolean)
char? : (any -> boolean)

```

### Strings

```

format : (string any ... -> string)
list->string : ((listof char) -> string)

```

```

make-string : (nat char -> string)
string : (char ... -> string)
string->list : (string -> (listof char))
string->number : (string -> (union number false))
string->symbol : (string -> symbol)
string-append : (string ... -> string)
string-ci<=? : (string string string ... -> boolean)
string-ci<? : (string string string ... -> boolean)
string-ci=? : (string string string ... -> boolean)
string-ci>=? : (string string string ... -> boolean)
string-ci>? : (string string string ... -> boolean)
string-copy : (string -> string)
string-length : (string -> nat)
string-ref : (string nat -> char)
string<=? : (string string string ... -> boolean)
string<? : (string string string ... -> boolean)
string=? : (string string string ... -> boolean)
string>=? : (string string string ... -> boolean)
string>? : (string string string ... -> boolean)
string? : (any -> boolean)
substring : (string nat nat -> string)

```

### Images

```

image=? : (image image -> boolean)
image? : (any -> boolean)

```

### Misc

```

=~ : (real real non-negative-real -> boolean)
eof : eof
eof-object? : (any -> boolean)
eq? : (any any -> boolean)
equal? : (any any -> boolean)
equal~? : (any any non-negative-real -> boolean)
eqv? : (any any -> boolean)
error : (symbol string -> void)
exit : (-> void)
identity : (any -> any)
struct? : (any -> boolean)

```

## 1.1 define

---

```
(define (id id id ...) expr)
```

Defines a function. The first *id* inside the parentheses is the name of the function. All remaining *ids* are the names of the function's arguments. The *expr* is the body of the

function, evaluated whenever the function is called. The name of the function cannot be that of a primitive or another definition.

---

```
(define id expr)
```

Defines a constant *id* as a synonym for the value produced by *expr*. The defined name cannot be that of a primitive or another definition, and *id* itself must not appear in *expr*.

---

```
(define id (lambda (id id ...) expr))
```

An alternate form for defining functions. The first *id* is the name of the function. The *ids* in parentheses are the names of the function's arguments, and the *expr* is the body of the function, which evaluated whenever the function is called. The name of the function cannot be that of a primitive or another definition.

---

lambda

The lambda keyword can only be used with define in the alternative function-definition syntax.

## 1.2 define-struct

---

```
(define-struct structid (fieldid ...))
```

Define a new type of structure. The structure's fields are named by the *fieldids* in parentheses. After evaluation of a define-struct form, a set of new primitives is available for creation, extraction, and type-like queries:

- *make-structid* : takes a number of arguments equal to the number of fields in the structure type, and creates a new instance of the structure type.
- *structid-fieldid* : takes an instance of the structure and returns the field named by *structid*.
- *structid?* : takes any value, and returns `true` if the value is an instance of the structure type.
- *structid* : an identifier representing the structure type, but never used directly.

The created names must not be the same as a primitive or another defined name.

### 1.3 Function Calls

---

```
(id expr expr ...)
```

Calls a function. The `id` must refer to a defined function, and the `exprs` are evaluated from left to right to produce the values that are passed as arguments to the function. The result of the function call is the result of evaluating the function's body with every instance of an argument name replaced by the value passed for that argument. The number of argument `exprs` must be the same as the number of arguments expected by the function.

---

```
(#%app id expr expr ...)
```

A function call can be written with `%app`, though it's practically never written that way.

### 1.4 Primitive Calls

---

```
(prim-op expr ...)
```

Like a function call, but for a primitive operation. The `exprs` are evaluated from left to right, and passed as arguments to the primitive operation named by `prim-op`. A `define-struct` form creates new primitives.

### 1.5 cond

---

```
(cond [expr expr] ... [expr expr])
```

A `cond` form contains one or more "lines" that are surrounded by parentheses or square brackets. Each line contains two `exprs`: a question `expr` and an answer `expr`.

The lines are considered in order. To evaluate a line, first evaluate the question `expr`. If the result is `true`, then the result of the whole `cond` expression is the result of evaluating the answer `expr` of the same line. If the result of evaluating the question `expr` is `false`, the line is discarded and evaluation proceeds with the next line.

If the result of a question `expr` is neither `true` nor `false`, it is an error. If none of the question `exprs` evaluates to `true`, it is also an error.

---

```
(cond [expr expr] ... [else expr])
```

This form of `cond` is similar to the prior one, except that the final `else` clause is always taken if no prior line's test expression evaluates to `true`. In other words, `else` acts like `true`, so there is no possibility to “fall off the end” of the `cond` form.

---

`else`

The `else` keyword can be used only with `cond`.

## 1.6 `if`

---

`(if expr expr expr)`

The first `expr` (known as the “test” `expr`) is evaluated. If it evaluates to `true`, the result of the `if` expression is the result of evaluating the second `expr` (often called the “then” `expr`). If the test `expr` evaluates to `false`, the result of the `if` expression is the result of evaluating the third `expr` (known as the “else” `expr`). If the result of evaluating the test `expr` is neither `true` nor `false`, it is an error.

## 1.7 `and`

---

`(and expr expr expr ...)`

The `exprs` are evaluated from left to right. If the first `expr` evaluates to `false`, the `and` expression immediately evaluates to `false`. If the first `expr` evaluates to `true`, the next expression is considered. If all `exprs` evaluate to `true`, the `and` expression evaluates to `true`. If any of the expressions evaluate to a value other than `true` or `false`, it is an error.

## 1.8 `or`

---

`(or expr expr expr ...)`

The `exprs` are evaluated from left to right. If the first `expr` evaluates to `true`, the `or` expression immediately evaluates to `true`. If the first `expr` evaluates to `false`, the next expression is considered. If all `exprs` evaluate to `false`, the `or` expression evaluates to `false`. If any of the expressions evaluate to a value other than `true` or `false`, it is an error.

## 1.9 Test Cases

---

`(check-expect expr expr)`

A test case to check that the first *expr* produces the same value as the second *expr*, where the latter is normally an immediate value.

---

`(check-within expr expr expr)`

Like `check-expect`, but with an extra expression that produces a number *delta*. The test case checks that each number in the result of the first *expr* is within *delta* of each corresponding number from the second *expr*.

---

`(check-error expr expr)`

A test case to check that the first *expr* signals an error, where the error messages matches the string produced by the second *expr*.

## 1.10 `empty`

---

`empty : empty?`

The empty list.

## 1.11 Identifiers

---

`id`

An `id` refers to a defined constant or argument within a function body. If no definition or argument matches the `id` name, an error is reported. Similarly, if `id` matches the name of a defined function or primitive operation, an error is reported.

## 1.12 Symbols

---

`'id`  
`(quote id)`

A quoted *id* is a symbol. A symbol is a constant, like `0` and `empty`.

Normally, a symbol is written with a `'`, like `'apple`, but it can also be written with quote, like `(quote apple)`.

The *id* for a symbol is a sequence of characters not including a space or one of the following:

```
" , ' ( ) [ ] { } | ; #
```

### 1.13 true and false

---

```
true : boolean?
```

The true value.

---

```
false : boolean?
```

The false value.

### 1.14 require

---

```
(require string)
```

Makes the definitions of the module specified by *string* available in the current module (i.e., current file), where *string* refers to a file relative to the enclosing file.

The *string* is constrained in several ways to avoid problems with different path conventions on different platforms: a `/` is a directory separator, `.` always means the current directory, `..` always means the parent directory, path elements can use only `a` through `z` (uppercase or lowercase), `0` through `9`, `=`, `-`, and `._`, and the string cannot be empty or contain a leading or trailing `/`.

---

```
(require (lib string string ...))
```

Accesses a file in an installed library, making its definitions available in the current module (i.e., current file). The first *string* names the library file, and the remaining *strings* name the collection (and sub-collection, and so on) where the file is installed. Each string is constrained in the same way as for the `(require string)` form.

---

```
(require (planet string (string string number number)))
```

Accesses a library that is distributed on the internet via the PLaneT server, making it definitions available in the current module (i.e., current file).

## 1.15 Primitive Operations

---

```
* : (num num num ... -> num)
```

Purpose: to compute the product of all of the input numbers

---

```
+ : (num num num ... -> num)
```

Purpose: to compute the sum of the input numbers

---

```
- : (num num ... -> num)
```

Purpose: to subtract the second (and following) number(s) from the first; negate the number if there is only one argument

---

```
/ : (num num num ... -> num)
```

Purpose: to divide the first by the second (and all following) number(s); try (/ 3 4) and (/ 3 2 2) only the first number can be zero.

---

```
< : (real real real ... -> boolean)
```

Purpose: to compare real numbers for less-than

---

```
<= : (real real real ... -> boolean)
```

Purpose: to compare real numbers for less-than or equality

---

```
= : (num num num ... -> boolean)
```

Purpose: to compare numbers for equality

---

```
> : (real real real ... -> boolean)
```



Purpose: to compare real numbers for greater-than

---

```
>= : (real real ... -> boolean)
```

Purpose: to compare real numbers for greater-than or equality

---

```
abs : (real -> real)
```

Purpose: to compute the absolute value of a real number

---

```
acos : (num -> num)
```

Purpose: to compute the arccosine (inverse of cos) of a number

---

```
add1 : (number -> number)
```

Purpose: to compute a number one larger than a given number

---

```
angle : (num -> real)
```

Purpose: to extract the angle from a complex number

---

```
asin : (num -> num)
```

Purpose: to compute the arcsine (inverse of sin) of a number

---

```
atan : (num -> num)
```

Purpose: to compute the arctan (inverse of tan) of a number

---

```
ceiling : (real -> int)
```

Purpose: to determine the closest integer above a real number

---

```
complex? : (any -> boolean)
```

Purpose: to determine whether some value is complex

---

`conjugate` : (num -> num)

Purpose: to compute the conjugate of a complex number

---

`cos` : (num -> num)

Purpose: to compute the cosine of a number (radians)

---

`cosh` : (num -> num)

Purpose: to compute the hyperbolic cosine of a number

---

`current-seconds` : (-> int)

Purpose: to compute the current time in seconds elapsed (since a platform-specific starting date)

---

`denominator` : (rat -> int)

Purpose: to compute the denominator of a rational

---

`e` : real

Purpose: Euler's number

---

`even?` : (integer -> boolean)

Purpose: to determine if some value is even or not

---

`exact->inexact` : (num -> num)

Purpose: to convert an exact number to an inexact one

---

`exact?` : (num -> boolean)

Purpose: to determine whether some number is exact

---

`exp` : (num -> num)

Purpose: to compute e raised to a number

---

```
expt : (num num -> num)
```

Purpose: to compute the power of the first to the second number

---

```
floor : (real -> int)
```

Purpose: to determine the closest integer below a real number

---

```
gcd : (int int ... -> int)
```

Purpose: to compute the greatest common divisor

---

```
imag-part : (num -> real)
```

Purpose: to extract the imaginary part from a complex number

---

```
inexact->exact : (num -> num)
```

Purpose: to approximate an inexact number by an exact one

---

```
inexact? : (num -> boolean)
```

Purpose: to determine whether some number is inexact

---

```
integer->char : (int -> char)
```

Purpose: to lookup the character that corresponds to the given integer in the ASCII table (if any)

---

```
integer? : (any -> boolean)
```

Purpose: to determine whether some value is an integer (exact or inexact)

---

```
lcm : (int int ... -> int)
```

Purpose: to compute the least common multiple of two integers

---

`log` : (num -> num)

Purpose: to compute the base-e logarithm of a number

---

`magnitude` : (num -> real)

Purpose: to determine the magnitude of a complex number

---

`make-polar` : (real real -> num)

Purpose: to create a complex from a magnitude and angle

---

`max` : (real real ... -> real)

Purpose: to determine the largest number

---

`min` : (real real ... -> real)

Purpose: to determine the smallest number

---

`modulo` : (int int -> int)

Purpose: to find the remainder of the division of the first number by the second; try (modulo 4 3) (modulo 4 -3)

---

`negative?` : (number -> boolean)

Purpose: to determine if some value is strictly smaller than zero

---

`number->string` : (num -> string)

Purpose: to convert a number to a string

---

`number?` : (any -> boolean)

Purpose: to determine whether some value is a number

---

`numerator` : (rat -> int)

Purpose: to compute the numerator of a rational

---

```
odd? : (integer -> boolean)
```

Purpose: to determine if some value is odd or not

---

```
pi : real
```

Purpose: the ratio of a circle's circumference to its diameter

---

```
positive? : (number -> boolean)
```

Purpose: to determine if some value is strictly larger than zero

---

```
quotient : (int int -> int)
```

Purpose: to divide the first integer into the second; try (quotient 3 4) and (quotient 4 3)

---

```
random : (int -> int)
```

Purpose: to generate a random natural number less than some given integer

---

```
rational? : (any -> boolean)
```

Purpose: to determine whether some value is a rational number

---

```
real-part : (num -> real)
```

Purpose: to extract the real part from a complex number

---

```
real? : (any -> boolean)
```

Purpose: to determine whether some value is a real number

---

```
remainder : (int int -> int)
```

Purpose: to determine the remainder of dividing the first by the second integer

---

```
round : (real -> int)
```

Purpose: to round a real number to an integer (rounds to even to break ties)

---

```
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
```

Purpose: to compute the sign of a real number

---

```
sin : (num -> num)
```

Purpose: to compute the sine of a number (radians)

---

```
sinh : (num -> num)
```

Purpose: to compute the hyperbolic sine of a number

---

```
sqr : (num -> num)
```

Purpose: to compute the square of a number

---

```
sqrt : (num -> num)
```

Purpose: to compute the square root of a number

---

```
sub1 : (number -> number)
```

Purpose: to compute a number one smaller than a given number

---

```
tan : (num -> num)
```

Purpose: to compute the tangent of a number (radians)

---

```
zero? : (number -> boolean)
```

Purpose: to determine if some value is zero or not

---

```
boolean=? : (boolean boolean -> boolean)
```

Purpose: to determine whether two booleans are equal

---

`boolean?` : (any -> boolean)

Purpose: to determine whether some value is a boolean

---

`false?` : (any -> boolean)

Purpose: to determine whether a value is false

---

`not` : (boolean -> boolean)

Purpose: to compute the negation of a boolean value

---

`symbol->string` : (symbol -> string)

Purpose: to convert a symbol to a string

---

`symbol=?` : (symbol symbol -> boolean)

Purpose: to determine whether two symbols are equal

---

`symbol?` : (any -> boolean)

Purpose: to determine whether some value is a symbol

---

`append` : ((listof any)  
          (listof any)  
          (listof any)  
          ...  
          ->  
          (listof any))

Purpose: to create a single list from several, by juxtaposition of the items

---

`assq` : (X  
         (listof (cons X Y))  
         ->  
         (union false (cons X Y)))

Purpose: to determine whether some item is the first item of a pair in a list of pairs

---

```
caaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        W)
```

Purpose: to select the first item of the first list in the first list of a list

---

```
caadr : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
```

Purpose: to select the first item of the first list in a list

---

```
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
```

Purpose: to select the second item of the first list of a list

---

```
caddr : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
cadr : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
car : ((cons Y (listof X)) -> Y)
```



Purpose: to select the first item of a non-empty list

---

```
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
                (listof X))
         ->
         (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
         ->
         (listof Y))
```

Purpose: to select the rest of the first list in the rest of a list

---

```
cdar : ((cons (cons Z (listof Y)) (listof X))
        ->
        (listof Y))
```

Purpose: to select the rest of a non-empty list in a list

---

```
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         (listof Y))
```

Purpose: to select the rest of the rest of the first list of a list

---

```
cdddr : ((cons W (cons Z (cons Y (listof X))))
         ->
         (listof X))
```

Purpose: to select the rest of the rest of the rest of a list

---

```
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
```

Purpose: to select the rest of the rest of a list

---

```
cdr : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
cons : (X (listof X) -> (listof X))
```

Purpose: to construct a list

---

```
cons? : (any -> boolean)
```

Purpose: to determine whether some value is a constructed list

---

```
eighth : ((listof Y) -> Y)
```

Purpose: to select the eighth item of a non-empty list

---

```
empty? : (any -> boolean)
```

Purpose: to determine whether some value is the empty list

---

```
fifth : ((listof Y) -> Y)
```

Purpose: to select the fifth item of a non-empty list

---

```
first : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
fourth : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
length : ((listof any) -> number)
```

Purpose: to compute the number of items on a list

---

```
list : (any ... -> (listof any))
```

Purpose: to construct a list of its arguments

---

`list*` : (any ... (listof any) -> (listof any))

Purpose: to construct a list by adding multiple items to a list

---

`list-ref` : ((listof X) natural-number -> X)

Purpose: to extract the indexed item from the list

---

`member` : (any (listof any) -> boolean)

Purpose: to determine whether some value is on the list (comparing values with equal?)

---

`memq` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on some list (comparing values with eq?)

---

`memv` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on the list (comparing values with eqv?)

---

`null` : empty

Purpose: the empty list

---

`null?` : (any -> boolean)

Purpose: to determine whether some value is the empty list

---

`pair?` : (any -> boolean)

Purpose: to determine whether some value is a constructed list

---

`rest` : ((cons Y (listof X)) -> (listof X))

Purpose: to select the rest of a non-empty list

---

`reverse` : ((listof any) -> list)

Purpose: to create a reversed version of a list

---

`second` : ((cons Z (cons Y (listof X))) -> Y)

Purpose: to select the second item of a non-empty list

---

`seventh` : ((listof Y) -> Y)

Purpose: to select the seventh item of a non-empty list

---

`sixth` : ((listof Y) -> Y)

Purpose: to select the sixth item of a non-empty list

---

`third` : ((cons W (cons Z (cons Y (listof X)))) -> Y)

Purpose: to select the third item of a non-empty list

---

`make-posn` : (number number -> posn)

Purpose: to construct a posn

---

`posn-x` : (posn -> number)

Purpose: to extract the x component of a posn

---

`posn-y` : (posn -> number)

Purpose: to extract the y component of a posn

---

`posn?` : (anything -> boolean)

Purpose: to determine if its input is a posn

---

`char->integer` : (char -> integer)

Purpose: to lookup the number that corresponds to the given character in the ASCII table (if any)

---

`char-alphabetic?` : (char -> boolean)

Purpose: to determine whether a character represents an alphabetic character

---

`char-ci<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it) in a case-insensitive manner

---

`char-ci<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another in a case-insensitive manner

---

`char-ci=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal in a case-insensitive manner

---

`char-ci>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it) in a case-insensitive manner

---

`char-ci>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another in a case-insensitive manner

---

`char-downcase` : (char -> char)

Purpose: to determine the equivalent lower-case character

---

`char-lower-case?` : (char -> boolean)

Purpose: to determine whether a character is a lower-case character

---

`char-numeric?` : (char -> boolean)

Purpose: to determine whether a character represents a digit

---

`char-upcase` : (char -> char)

Purpose: to determine the equivalent upper-case character

---

`char-upper-case?` : (char -> boolean)

Purpose: to determine whether a character is an upper-case character

---

`char-whitespace?` : (char -> boolean)

Purpose: to determine whether a character represents space

---

`char<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it)

---

`char<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another

---

`char=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal

---

`char>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it)

---

`char>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another

---

`char?` : (any -> boolean)

Purpose: to determine whether a value is a character

---

`format` : (string any ... -> string)

Purpose: to format a string, possibly embedding values

---

`list->string` : ((listof char) -> string)

Purpose: to convert a s list of characters into a string

---

```
make-string : (nat char -> string)
```

Purpose: to produce a string of given length from a single given character

---

```
string : (char ... -> string)
```

Purpose: (string c1 c2 ...) builds a string

---

```
string->list : (string -> (listof char))
```

Purpose: to convert a string into a list of characters

---

```
string->number : (string -> (union number false))
```

Purpose: to convert a string into a number, produce false if impossible

---

```
string->symbol : (string -> symbol)
```

Purpose: to convert a string into a symbol

---

```
string-append : (string ... -> string)
```

Purpose: to juxtapose the characters of several strings

---

```
string-ci<=? : (string string string ... -> boolean)
```

Purpose: to determine whether one string alphabetically precedes another (or is equal to it) in a case-insensitive manner

---

```
string-ci<? : (string string string ... -> boolean)
```

Purpose: to determine whether one string alphabetically precedes another in a case-insensitive manner

---

```
string-ci=? : (string string string ... -> boolean)
```

Purpose: to compare two strings character-wise in a case-insensitive manner

---

`string-ci>=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it) in a case-insensitive manner

---

`string-ci>?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another in a case-insensitive manner

---

`string-copy` : (string -> string)

Purpose: to copy a string

---

`string-length` : (string -> nat)

Purpose: to determine the length of a string

---

`string-ref` : (string nat -> char)

Purpose: to extract the i-th character from a string

---

`string<=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

---

`string<?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another

---

`string=?` : (string string string ... -> boolean)

Purpose: to compare two strings character-wise

---

`string>=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it)

---



`string>? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another

---

`string? : (any -> boolean)`

Purpose: to determine whether a value is a string

---

`substring : (string nat nat -> string)`

Purpose: to extract the substring starting at a 0-based index up to the second 0-based index (exclusive)

---

`image=? : (image image -> boolean)`

Purpose: to determine whether two images are equal

---

`image? : (any -> boolean)`

Purpose: to determine whether a value is an image

---

`=~ : (real real non-negative-real -> boolean)`

Purpose: to check whether two real numbers are within some amount (the third argument) of either other

---

`eof : eof`

Purpose: the end-of-file value

---

`eof-object? : (any -> boolean)`

Purpose: to determine whether some value is the end-of-file value

---

`eq? : (any any -> boolean)`

Purpose: to compare two values

---

`equal? : (any any -> boolean)`

Purpose: to determine whether two values are structurally equal

---

```
equal~? : (any any non-negative-real -> boolean)
```

Purpose: to compare like equal? on the first two arguments, except using =~ in the case of real numbers

---

```
eqv? : (any any -> boolean)
```

Purpose: to compare two values

---

```
error : (symbol string -> void)
```

Purpose: to signal an error

---

```
exit : (-> void)
```

Purpose: to exit the running program

---

```
identity : (any -> any)
```

Purpose: to return the argument unchanged

---

```
struct? : (any -> boolean)
```

Purpose: to determine whether some value is a structure

## 2 Beginning Student with List Abbreviations

```
program = def-or-expr ...

def-or-expr = definition
             | expr
             | test-case
             | library-require

definition = (define (id id id ...) expr)
             | (define id expr)
             | (define id (lambda (id id ...) expr))
             | (define-struct id (id ...))

expr = (id expr expr ...) ; function call
       | (prim-op expr ...) ; primitive operation call
       | (cond [expr expr] ... [expr expr])
       | (cond [expr expr] ... [else expr])
       | (if expr expr expr)
       | (and expr expr expr ...)
       | (or expr expr expr ...)
       | empty
       | id
       | 'quoted ; quoted value
       | 'quasiquoted ; quasiquote
       | number
       | true
       | false
       | string
       | character

quoted = id
        | number
        | string
        | character
        | (quoted ...)
        | 'quoted
        | 'quoted
        | ,quoted
        | ,@quoted

quasiquoted = id
             | number
             | string
             | character
```

```

| (quasiquoted ...)
| 'quasiquoted
| `quasiquoted
| ,expr
| ,@expr

test-case = (check-expect expr expr)
| (check-within expr expr expr)
| (check-error expr expr)

library-require = (require string)
| (require (lib string string ...))
| (require (planet string package))

package = (string string number number)

```

An *id* is a sequence of characters not including a space or one of the following:

```
" , ' ( ) [ ] { } | ; #
```

A *number* is a number such as 123, 3/2, or 5.5.

A *string* is enclosed by a pair of `"`. Unlike symbols, strings may be split into characters and manipulated by a variety of primitive functions. For example, "abcdef", "This is a string", and "This is a string with \" inside" are all strings.

A *character* begins with `#\` and has the name of the character. For example, `#\a`, `#\b`, and `#\space` are characters.

A *prim-op* is one of:

**Numbers: Integers, Rationals, Reals, Complex, Exacts, Inexacts**

```

* : (num num num ... -> num)
+ : (num num num ... -> num)
- : (num num ... -> num)
/ : (num num num ... -> num)
< : (real real real ... -> boolean)
<= : (real real real ... -> boolean)
= : (num num num ... -> boolean)
> : (real real real ... -> boolean)
>= : (real real ... -> boolean)
abs : (real -> real)
acos : (num -> num)
add1 : (number -> number)
angle : (num -> real)
asin : (num -> num)
atan : (num -> num)
ceiling : (real -> int)

```

```

complex? : (any -> boolean)
conjugate : (num -> num)
cos : (num -> num)
cosh : (num -> num)
current-seconds : (-> int)
denominator : (rat -> int)
e : real
even? : (integer -> boolean)
exact->inexact : (num -> num)
exact? : (num -> boolean)
exp : (num -> num)
expt : (num num -> num)
floor : (real -> int)
gcd : (int int ... -> int)
imag-part : (num -> real)
inexact->exact : (num -> num)
inexact? : (num -> boolean)
integer->char : (int -> char)
integer? : (any -> boolean)
lcm : (int int ... -> int)
log : (num -> num)
magnitude : (num -> real)
make-polar : (real real -> num)
max : (real real ... -> real)
min : (real real ... -> real)
modulo : (int int -> int)
negative? : (number -> boolean)
number->string : (num -> string)
number? : (any -> boolean)
numerator : (rat -> int)
odd? : (integer -> boolean)
pi : real
positive? : (number -> boolean)
quotient : (int int -> int)
random : (int -> int)
rational? : (any -> boolean)
real-part : (num -> real)
real? : (any -> boolean)
remainder : (int int -> int)
round : (real -> int)
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
sin : (num -> num)
sinh : (num -> num)
sqr : (num -> num)
sqrt : (num -> num)
sub1 : (number -> number)

```

```
tan : (num -> num)
zero? : (number -> boolean)
```

### Booleans

```
boolean=? : (boolean boolean -> boolean)
boolean? : (any -> boolean)
false? : (any -> boolean)
not : (boolean -> boolean)
```

### Symbols

```
symbol->string : (symbol -> string)
symbol=? : (symbol symbol -> boolean)
symbol? : (any -> boolean)
```

### Lists

```
append : ((listof any)
           (listof any)
           (listof any)
           ...
           ->
           (listof any))
assq : (X
        (listof (cons X Y))
        ->
        (union false (cons X Y)))
caaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         W)
caadr : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         Z)
caddr : ((listof Y) -> Y)
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
cadr : ((cons Z (cons Y (listof X))) -> Y)
car : ((cons Y (listof X)) -> Y)
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
```

```

cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
->
(listof Y))
cdar : ((cons (cons Z (listof Y)) (listof X))
->
(listof Y))
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
->
(listof Y))
cdddr : ((cons W (cons Z (cons Y (listof X))))
->
(listof X))
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
cdr : ((cons Y (listof X)) -> (listof X))
cons : (X (listof X) -> (listof X))
cons? : (any -> boolean)
eighth : ((listof Y) -> Y)
empty? : (any -> boolean)
fifth : ((listof Y) -> Y)
first : ((cons Y (listof X)) -> Y)
fourth : ((listof Y) -> Y)
length : ((listof any) -> number)
list : (any ... -> (listof any))
list* : (any ... (listof any) -> (listof any))
list-ref : ((listof X) natural-number -> X)
member : (any (listof any) -> boolean)
memq : (any (listof any) -> (union false list))
memv : (any (listof any) -> (union false list))
null : empty
null? : (any -> boolean)
pair? : (any -> boolean)
rest : ((cons Y (listof X)) -> (listof X))
reverse : ((listof any) -> list)
second : ((cons Z (cons Y (listof X))) -> Y)
seventh : ((listof Y) -> Y)
sixth : ((listof Y) -> Y)
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)

```

### Posns

```

make-posn : (number number -> posn)
posn-x : (posn -> number)
posn-y : (posn -> number)
posn? : (anything -> boolean)

```

### Characters

```

char->integer : (char -> integer)
char-alphabetic? : (char -> boolean)
char-ci<=? : (char char char ... -> boolean)

```

```

char-ci<? : (char char char ... -> boolean)
char-ci=? : (char char char ... -> boolean)
char-ci>=? : (char char char ... -> boolean)
char-ci>? : (char char char ... -> boolean)
char-downcase : (char -> char)
char-lower-case? : (char -> boolean)
char-numeric? : (char -> boolean)
char-upcase : (char -> char)
char-upper-case? : (char -> boolean)
char-whitespace? : (char -> boolean)
char<=? : (char char char ... -> boolean)
char<? : (char char char ... -> boolean)
char=? : (char char char ... -> boolean)
char>=? : (char char char ... -> boolean)
char>? : (char char char ... -> boolean)
char? : (any -> boolean)

```

### Strings

```

format : (string any ... -> string)
list->string : ((listof char) -> string)
make-string : (nat char -> string)
string : (char ... -> string)
string->list : (string -> (listof char))
string->number : (string -> (union number false))
string->symbol : (string -> symbol)
string-append : (string ... -> string)
string-ci<=? : (string string string ... -> boolean)
string-ci<? : (string string string ... -> boolean)
string-ci=? : (string string string ... -> boolean)
string-ci>=? : (string string string ... -> boolean)
string-ci>? : (string string string ... -> boolean)
string-copy : (string -> string)
string-length : (string -> nat)
string-ref : (string nat -> char)
string<=? : (string string string ... -> boolean)
string<? : (string string string ... -> boolean)
string=? : (string string string ... -> boolean)
string>=? : (string string string ... -> boolean)
string>? : (string string string ... -> boolean)
string? : (any -> boolean)
substring : (string nat nat -> string)

```

### Images

```

image=? : (image image -> boolean)
image? : (any -> boolean)

```

### Misc

```

=~/ : (real real non-negative-real -> boolean)
eof : eof

```



```
eof-object? : (any -> boolean)
eq? : (any any -> boolean)
equal? : (any any -> boolean)
equal~? : (any any non-negative-real -> boolean)
eqv? : (any any -> boolean)
error : (symbol string -> void)
exit : (-> void)
identity : (any -> any)
struct? : (any -> boolean)
```

## 2.1 Quote

---

```
'quoted

```

Creates symbols and abbreviates nested lists.

Normally, this form is written with a quote, like '(apple banana), but it can also be written with quote, like (quote (apple banana)).

## 2.2 Quasiquote

---

```
'quasiquoted
(quasiquote quasiquoted)
```

Creates symbols and abbreviates nested lists, but also allows escaping to expression “unquotes.”

Normally, this form is written with a backquote, ```, like `(apple ,(+ 1 2))`, but it can also be written with quasiquote, like (quasiquote (apple ,(+ 1 2))).

---

```
,quasiquoted
(unquote expr)
```

Under a single quasiquote, `,expr` escapes from the quote to include an evaluated expression whose result is inserted into the abbreviated list.

Under multiple quasiquotes, `,expr` is really `,quasiquoted`, decrementing the quasiquote count by one for `quasiquoted`.

Normally, an unquote is written with `,`, but it can also be written with unquote.

---

```
,@quasiquoted  
(unquote-splicing expr)
```

Under a single quasiquote, `,@expr` escapes from the quote to include an evaluated expression whose result is a list to splice into the abbreviated list.

Under multiple quasiquotes, a splicing unquote is like an unquote; that is, it decrements the quasiquote count by one.

Normally, a splicing unquote is written with `,,` but it can also be written with `unquote-splicing`.

## 2.3 Primitive Operations

---

```
* : (num num num ... -> num)
```

Purpose: to compute the product of all of the input numbers

---

```
+ : (num num num ... -> num)
```

Purpose: to compute the sum of the input numbers

---

```
- : (num num ... -> num)
```

Purpose: to subtract the second (and following) number(s) from the first; negate the number if there is only one argument

---

```
/ : (num num num ... -> num)
```

Purpose: to divide the first by the second (and all following) number(s); try `(/ 3 4)` and `(/ 3 2 2)` only the first number can be zero.

---

```
< : (real real real ... -> boolean)
```

Purpose: to compare real numbers for less-than

---

```
<= : (real real real ... -> boolean)
```

Purpose: to compare real numbers for less-than or equality

---

`= : (num num num ... -> boolean)`

Purpose: to compare numbers for equality

---

`> : (real real real ... -> boolean)`

Purpose: to compare real numbers for greater-than

---

`>= : (real real ... -> boolean)`

Purpose: to compare real numbers for greater-than or equality

---

`abs : (real -> real)`

Purpose: to compute the absolute value of a real number

---

`acos : (num -> num)`

Purpose: to compute the arccosine (inverse of cos) of a number

---

`add1 : (number -> number)`

Purpose: to compute a number one larger than a given number

---

`angle : (num -> real)`

Purpose: to extract the angle from a complex number

---

`asin : (num -> num)`

Purpose: to compute the arcsine (inverse of sin) of a number

---

`atan : (num -> num)`

Purpose: to compute the arctan (inverse of tan) of a number

---

`ceiling : (real -> int)`

Purpose: to determine the closest integer above a real number

---

`complex?` : (any -> boolean)

Purpose: to determine whether some value is complex

---

`conjugate` : (num -> num)

Purpose: to compute the conjugate of a complex number

---

`cos` : (num -> num)

Purpose: to compute the cosine of a number (radians)

---

`cosh` : (num -> num)

Purpose: to compute the hyperbolic cosine of a number

---

`current-seconds` : (-> int)

Purpose: to compute the current time in seconds elapsed (since a platform-specific starting date)

---

`denominator` : (rat -> int)

Purpose: to compute the denominator of a rational

---

`e` : real

Purpose: Euler's number

---

`even?` : (integer -> boolean)

Purpose: to determine if some value is even or not

---

`exact->inexact` : (num -> num)

Purpose: to convert an exact number to an inexact one

---

`exact? : (num -> boolean)`

Purpose: to determine whether some number is exact

---

`exp : (num -> num)`

Purpose: to compute e raised to a number

---

`expt : (num num -> num)`

Purpose: to compute the power of the first to the second number

---

`floor : (real -> int)`

Purpose: to determine the closest integer below a real number

---

`gcd : (int int ... -> int)`

Purpose: to compute the greatest common divisor

---

`imag-part : (num -> real)`

Purpose: to extract the imaginary part from a complex number

---

`inexact->exact : (num -> num)`

Purpose: to approximate an inexact number by an exact one

---

`inexact? : (num -> boolean)`

Purpose: to determine whether some number is inexact

---

`integer->char : (int -> char)`

Purpose: to lookup the character that corresponds to the given integer in the ASCII table (if any)

---

`integer? : (any -> boolean)`

Purpose: to determine whether some value is an integer (exact or inexact)

---

```
lcm : (int int ... -> int)
```

Purpose: to compute the least common multiple of two integers

---

```
log : (num -> num)
```

Purpose: to compute the base-e logarithm of a number

---

```
magnitude : (num -> real)
```

Purpose: to determine the magnitude of a complex number

---

```
make-polar : (real real -> num)
```

Purpose: to create a complex from a magnitude and angle

---

```
max : (real real ... -> real)
```

Purpose: to determine the largest number

---

```
min : (real real ... -> real)
```

Purpose: to determine the smallest number

---

```
modulo : (int int -> int)
```

Purpose: to find the remainder of the division of the first number by the second; try (modulo 4 3) (modulo 4 -3)

---

```
negative? : (number -> boolean)
```

Purpose: to determine if some value is strictly smaller than zero

---

```
number->string : (num -> string)
```

Purpose: to convert a number to a string

---

`number?` : (any -> boolean)

Purpose: to determine whether some value is a number

---

`numerator` : (rat -> int)

Purpose: to compute the numerator of a rational

---

`odd?` : (integer -> boolean)

Purpose: to determine if some value is odd or not

---

`pi` : real

Purpose: the ratio of a circle's circumference to its diameter

---

`positive?` : (number -> boolean)

Purpose: to determine if some value is strictly larger than zero

---

`quotient` : (int int -> int)

Purpose: to divide the first integer into the second; try (quotient 3 4) and (quotient 4 3)

---

`random` : (int -> int)

Purpose: to generate a random natural number less than some given integer

---

`rational?` : (any -> boolean)

Purpose: to determine whether some value is a rational number

---

`real-part` : (num -> real)

Purpose: to extract the real part from a complex number

---

`real?` : (any -> boolean)

Purpose: to determine whether some value is a real number

---

```
remainder : (int int -> int)
```

Purpose: to determine the remainder of dividing the first by the second integer

---

```
round : (real -> int)
```

Purpose: to round a real number to an integer (rounds to even to break ties)

---

```
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
```

Purpose: to compute the sign of a real number

---

```
sin : (num -> num)
```

Purpose: to compute the sine of a number (radians)

---

```
sinh : (num -> num)
```

Purpose: to compute the hyperbolic sine of a number

---

```
sqr : (num -> num)
```

Purpose: to compute the square of a number

---

```
sqrt : (num -> num)
```

Purpose: to compute the square root of a number

---

```
sub1 : (number -> number)
```

Purpose: to compute a number one smaller than a given number

---

```
tan : (num -> num)
```

Purpose: to compute the tangent of a number (radians)

---



`zero? : (number -> boolean)`

Purpose: to determine if some value is zero or not

---

`boolean=? : (boolean boolean -> boolean)`

Purpose: to determine whether two booleans are equal

---

`boolean? : (any -> boolean)`

Purpose: to determine whether some value is a boolean

---

`false? : (any -> boolean)`

Purpose: to determine whether a value is false

---

`not : (boolean -> boolean)`

Purpose: to compute the negation of a boolean value

---

`symbol->string : (symbol -> string)`

Purpose: to convert a symbol to a string

---

`symbol=? : (symbol symbol -> boolean)`

Purpose: to determine whether two symbols are equal

---

`symbol? : (any -> boolean)`

Purpose: to determine whether some value is a symbol

---

`append : ((listof any)  
          (listof any)  
          (listof any)  
          ...  
          ->  
          (listof any))`

Purpose: to create a single list from several, by juxtaposition of the items

---

```
assq : (X
      (listof (cons X Y))
      ->
      (union false (cons X Y)))
```

Purpose: to determine whether some item is the first item of a pair in a list of pairs

---

```
caaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
        ->
        W)
```

Purpose: to select the first item of the first list in the first list of a list

---

```
caadr : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
```

Purpose: to select the first item of the first list in a list

---

```
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
```

Purpose: to select the second item of the first list of a list

---

```
caddr : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
cadr : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
car : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
        ->
        (listof Y))
```

Purpose: to select the rest of the first list in the rest of a list

---

```
cdar : ((cons (cons Z (listof Y)) (listof X))
        ->
        (listof Y))
```

Purpose: to select the rest of a non-empty list in a list

---

```
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         (listof Y))
```

Purpose: to select the rest of the rest of the first list of a list

---

```
cdddr : ((cons W (cons Z (cons Y (listof X))))
         ->
         (listof X))
```

Purpose: to select the rest of the rest of the rest of a list

---

```
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
```

Purpose: to select the rest of the rest of a list

---

```
cdr : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
cons : (X (listof X) -> (listof X))
```

Purpose: to construct a list

---

```
cons? : (any -> boolean)
```

Purpose: to determine whether some value is a constructed list

---

```
eighth : ((listof Y) -> Y)
```

Purpose: to select the eighth item of a non-empty list

---

```
empty? : (any -> boolean)
```

Purpose: to determine whether some value is the empty list

---

```
fifth : ((listof Y) -> Y)
```

Purpose: to select the fifth item of a non-empty list

---

```
first : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
fourth : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

`length` : ((listof any) -> number)

Purpose: to compute the number of items on a list

---

`list` : (any ... -> (listof any))

Purpose: to construct a list of its arguments

---

`list*` : (any ... (listof any) -> (listof any))

Purpose: to construct a list by adding multiple items to a list

---

`list-ref` : ((listof X) natural-number -> X)

Purpose: to extract the indexed item from the list

---

`member` : (any (listof any) -> boolean)

Purpose: to determine whether some value is on the list (comparing values with equal?)

---

`memq` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on some list (comparing values with eq?)

---

`memv` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on the list (comparing values with eqv?)

---

`null` : empty

Purpose: the empty list

---

`null?` : (any -> boolean)

Purpose: to determine whether some value is the empty list

---

`pair?` : (any -> boolean)

Purpose: to determine whether some value is a constructed list

---

```
rest : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
reverse : ((listof any) -> list)
```

Purpose: to create a reversed version of a list

---

```
second : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
seventh : ((listof Y) -> Y)
```

Purpose: to select the seventh item of a non-empty list

---

```
sixth : ((listof Y) -> Y)
```

Purpose: to select the sixth item of a non-empty list

---

```
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
make-posn : (number number -> posn)
```

Purpose: to construct a posn

---

```
posn-x : (posn -> number)
```

Purpose: to extract the x component of a posn

---

```
posn-y : (posn -> number)
```

Purpose: to extract the y component of a posn

---

```
posn? : (anything -> boolean)
```

Purpose: to determine if its input is a posn

---

`char->integer` : (char -> integer)

Purpose: to lookup the number that corresponds to the given character in the ASCII table (if any)

---

`char-alphabetic?` : (char -> boolean)

Purpose: to determine whether a character represents an alphabetic character

---

`char-ci<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it) in a case-insensitive manner

---

`char-ci<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another in a case-insensitive manner

---

`char-ci=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal in a case-insensitive manner

---

`char-ci>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it) in a case-insensitive manner

---

`char-ci>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another in a case-insensitive manner

---

`char-downcase` : (char -> char)

Purpose: to determine the equivalent lower-case character

---

`char-lower-case?` : (char -> boolean)

Purpose: to determine whether a character is a lower-case character

---

`char-numeric?` : (char -> boolean)

Purpose: to determine whether a character represents a digit

---

`char-upcase` : (char -> char)

Purpose: to determine the equivalent upper-case character

---

`char-upper-case?` : (char -> boolean)

Purpose: to determine whether a character is an upper-case character

---

`char-whitespace?` : (char -> boolean)

Purpose: to determine whether a character represents space

---

`char<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it)

---

`char<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another

---

`char=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal

---

`char>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it)

---

`char>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another

---



`char?` : (any -> boolean)

Purpose: to determine whether a value is a character

---

`format` : (string any ... -> string)

Purpose: to format a string, possibly embedding values

---

`list->string` : ((listof char) -> string)

Purpose: to convert a list of characters into a string

---

`make-string` : (nat char -> string)

Purpose: to produce a string of given length from a single given character

---

`string` : (char ... -> string)

Purpose: (string c1 c2 ...) builds a string

---

`string->list` : (string -> (listof char))

Purpose: to convert a string into a list of characters

---

`string->number` : (string -> (union number false))

Purpose: to convert a string into a number, produce false if impossible

---

`string->symbol` : (string -> symbol)

Purpose: to convert a string into a symbol

---

`string-append` : (string ... -> string)

Purpose: to juxtapose the characters of several strings

---

`string-ci<=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

in a case-insensitive manner

---

`string-ci<? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another in a case-insensitive manner

---

`string-ci=? : (string string string ... -> boolean)`

Purpose: to compare two strings character-wise in a case-insensitive manner

---

`string-ci>=? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it) in a case-insensitive manner

---

`string-ci>? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another in a case-insensitive manner

---

`string-copy : (string -> string)`

Purpose: to copy a string

---

`string-length : (string -> nat)`

Purpose: to determine the length of a string

---

`string-ref : (string nat -> char)`

Purpose: to extract the i-th character from a string

---

`string<=? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

---

`string<? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another

---

```
string=? : (string string string ... -> boolean)
```

Purpose: to compare two strings character-wise

---

```
string>=? : (string string string ... -> boolean)
```

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it)

---

```
string>? : (string string string ... -> boolean)
```

Purpose: to determine whether one string alphabetically succeeds another

---

```
string? : (any -> boolean)
```

Purpose: to determine whether a value is a string

---

```
substring : (string nat nat -> string)
```

Purpose: to extract the substring starting at a 0-based index up to the second 0-based index (exclusive)

---

```
image=? : (image image -> boolean)
```

Purpose: to determine whether two images are equal

---

```
image? : (any -> boolean)
```

Purpose: to determine whether a value is an image

---

```
=~ : (real real non-negative-real -> boolean)
```

Purpose: to check whether two real numbers are within some amount (the third argument) of either other

---

```
eof : eof
```

Purpose: the end-of-file value

---

`eof-object?` : (any -> boolean)

Purpose: to determine whether some value is the end-of-file value

---

`eq?` : (any any -> boolean)

Purpose: to compare two values

---

`equal?` : (any any -> boolean)

Purpose: to determine whether two values are structurally equal

---

`equal~?` : (any any non-negative-real -> boolean)

Purpose: to compare like `equal?` on the first two arguments, except using `=~` in the case of real numbers

---

`eqv?` : (any any -> boolean)

Purpose: to compare two values

---

`error` : (symbol string -> void)

Purpose: to signal an error

---

`exit` : (-> void)

Purpose: to exit the running program

---

`identity` : (any -> any)

Purpose: to return the argument unchanged

---

`struct?` : (any -> boolean)

Purpose: to determine whether some value is a structure

## 2.4 Unchanged Forms

---

```
(define (id id id ...) expr)  
(define id expr)  
(define id (lambda (id id ...) expr))  
lambda
```

The same as Beginning's define.

---

```
(define-struct structid (fieldid ...))
```

The same as Beginning's define-struct.

---

```
(cond [expr expr] ... [expr expr])  
else
```

The same as Beginning's cond.

---

```
(if expr expr expr)
```

The same as Beginning's if.

---

```
(and expr expr expr ...)  
(or expr expr expr ...)
```

The same as Beginning's and and or.

---

```
(check-expect expr expr)  
(check-within expr expr expr)  
(check-error expr expr)
```

The same as Beginning's check-expect, etc.

---

```
empty : empty?  
true : boolean?  
false : boolean?
```

Constants for the empty list, true, and false.

---

(require *string*)

The same as Beginning's require.

### 3 Intermediate Student

```
program = def-or-expr ...

def-or-expr = definition
            | expr
            | test-case
            | library-require

definition = (define (id id id ...) expr)
            | (define id expr)
            | (define id (lambda (id id ...) expr))
            | (define-struct id (id ...))

expr = (local [definition ...] expr)
      | (letrec ([id expr-for-let] ...) expr)
      | (let ([id expr-for-let] ...) expr)
      | (let* ([id expr-for-let] ...) expr)
      | (id expr expr ...) ; function call
      | (prim-op expr ...) ; primitive operation call
      | (cond [expr expr] ... [expr expr])
      | (cond [expr expr] ... [else expr])
      | (if expr expr expr)
      | (and expr expr expr ...)
      | (or expr expr expr ...)
      | (time expr)
      | empty
      | id ; identifier
      | prim-op ; primitive operation
      | 'id
      | 'quoted ; quoted value
      | 'quasiquoted ; quasiquote
      | number
      | true
      | false
      | string
      | character

expr-for-let = (lambda (id id ...) expr)
              | expr

quoted = id
        | number
        | string
        | character
```

```

| (quoted ...)
| 'quoted
| `quoted
| ,quoted
| ,@quoted

quasiquoted = id
| number
| string
| character
| (quasiquoted ...)
| 'quasiquoted
| `quasiquoted
| ,expr
| ,@expr

test-case = (check-expect expr expr)
| (check-within expr expr expr)
| (check-error expr expr)

library-require = (require string)
| (require (lib string string ...))
| (require (planet string package))

package = (string string number number)

```

An *id* is a sequence of characters not including a space or one of the following:

```
" , ' ` ( ) [ ] { } | ; #
```

A *number* is a number such as 123, 3/2, or 5.5.

A *string* is enclosed by a pair of `"`. Unlike symbols, strings may be split into characters and manipulated by a variety of primitive functions. For example, `"abcdef"`, `"This is a string"`, and `"This is a string with \" inside"` are all strings.

A *character* begins with `#\` and has the name of the character. For example, `#\a`, `#\b`, and `#\space` are characters.

A *prim-op* is one of:

**Numbers: Integers, Rationals, Reals, Complex, Exacts, Inexacts**

```

* : (num num num ... -> num)
+ : (num num num ... -> num)
- : (num num ... -> num)
/ : (num num num ... -> num)
< : (real real real ... -> boolean)
<= : (real real real ... -> boolean)

```



```

= : (num num num ... -> boolean)
> : (real real real ... -> boolean)
>= : (real real ... -> boolean)
abs : (real -> real)
acos : (num -> num)
add1 : (number -> number)
angle : (num -> real)
asin : (num -> num)
atan : (num -> num)
ceiling : (real -> int)
complex? : (any -> boolean)
conjugate : (num -> num)
cos : (num -> num)
cosh : (num -> num)
current-seconds : (-> int)
denominator : (rat -> int)
e : real
even? : (integer -> boolean)
exact->inexact : (num -> num)
exact? : (num -> boolean)
exp : (num -> num)
expt : (num num -> num)
floor : (real -> int)
gcd : (int int ... -> int)
imag-part : (num -> real)
inexact->exact : (num -> num)
inexact? : (num -> boolean)
integer->char : (int -> char)
integer? : (any -> boolean)
lcm : (int int ... -> int)
log : (num -> num)
magnitude : (num -> real)
make-polar : (real real -> num)
max : (real real ... -> real)
min : (real real ... -> real)
modulo : (int int -> int)
negative? : (number -> boolean)
number->string : (num -> string)
number? : (any -> boolean)
numerator : (rat -> int)
odd? : (integer -> boolean)
pi : real
positive? : (number -> boolean)
quotient : (int int -> int)
random : (int -> int)
rational? : (any -> boolean)

```

```

real-part : (num -> real)
real? : (any -> boolean)
remainder : (int int -> int)
round : (real -> int)
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
sin : (num -> num)
sinh : (num -> num)
sqr : (num -> num)
sqrt : (num -> num)
sub1 : (number -> number)
tan : (num -> num)
zero? : (number -> boolean)

```

### Booleans

```

boolean=? : (boolean boolean -> boolean)
boolean? : (any -> boolean)
false? : (any -> boolean)
not : (boolean -> boolean)

```

### Symbols

```

symbol->string : (symbol -> string)
symbol=? : (symbol symbol -> boolean)
symbol? : (any -> boolean)

```

### Lists

```

append : ((listof any)
          (listof any)
          (listof any)
          ...
          ->
          (listof any))
assq : (X
       (listof (cons X Y))
       ->
       (union false (cons X Y)))
caaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        W)
caadr : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)

```

```

caddr : ((listof Y) -> Y)
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
cadr  : ((cons Z (cons Y (listof X))) -> Y)
car   : ((cons Y (listof X)) -> Y)
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
         ->
         (listof Y))
cdar  : ((cons (cons Z (listof Y)) (listof X))
         ->
         (listof Y))
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         (listof Y))
cddddr : ((cons W (cons Z (cons Y (listof X))))
          ->
          (listof X))
cddr  : ((cons Z (cons Y (listof X))) -> (listof X))
cdr   : ((cons Y (listof X)) -> (listof X))
cons  : (X (listof X) -> (listof X))
cons? : (any -> boolean)
eighth : ((listof Y) -> Y)
empty? : (any -> boolean)
fifth  : ((listof Y) -> Y)
first  : ((cons Y (listof X)) -> Y)
fourth : ((listof Y) -> Y)
length : ((listof any) -> number)
list   : (any ... -> (listof any))
list*  : (any ... (listof any) -> (listof any))
list-ref : ((listof X) natural-number -> X)
member : (any (listof any) -> boolean)
memq   : (any (listof any) -> (union false list))
memv   : (any (listof any) -> (union false list))
null   : empty
null?  : (any -> boolean)
pair?  : (any -> boolean)
rest   : ((cons Y (listof X)) -> (listof X))
reverse : ((listof any) -> list)
second : ((cons Z (cons Y (listof X))) -> Y)
seventh : ((listof Y) -> Y)
sixth  : ((listof Y) -> Y)
third  : ((cons W (cons Z (cons Y (listof X)))) -> Y)

```

## Posns

```
make-posn : (number number -> posn)
posn-x : (posn -> number)
posn-y : (posn -> number)
posn? : (anything -> boolean)
```

## Characters

```
char->integer : (char -> integer)
char-alphabetic? : (char -> boolean)
char-ci<=? : (char char char ... -> boolean)
char-ci<? : (char char char ... -> boolean)
char-ci=? : (char char char ... -> boolean)
char-ci>=? : (char char char ... -> boolean)
char-ci>? : (char char char ... -> boolean)
char-downcase : (char -> char)
char-lower-case? : (char -> boolean)
char-numeric? : (char -> boolean)
char-upcase : (char -> char)
char-upper-case? : (char -> boolean)
char-whitespace? : (char -> boolean)
char<=? : (char char char ... -> boolean)
char<? : (char char char ... -> boolean)
char=? : (char char char ... -> boolean)
char>=? : (char char char ... -> boolean)
char>? : (char char char ... -> boolean)
char? : (any -> boolean)
```

## Strings

```
format : (string any ... -> string)
list->string : ((listof char) -> string)
make-string : (nat char -> string)
string : (char ... -> string)
string->list : (string -> (listof char))
string->number : (string -> (union number false))
string->symbol : (string -> symbol)
string-append : (string ... -> string)
string-ci<=? : (string string string ... -> boolean)
string-ci<? : (string string string ... -> boolean)
string-ci=? : (string string string ... -> boolean)
string-ci>=? : (string string string ... -> boolean)
string-ci>? : (string string string ... -> boolean)
string-copy : (string -> string)
string-length : (string -> nat)
string-ref : (string nat -> char)
string<=? : (string string string ... -> boolean)
string<? : (string string string ... -> boolean)
string=? : (string string string ... -> boolean)
string>=? : (string string string ... -> boolean)
```

```

string>? : (string string string ... -> boolean)
string? : (any -> boolean)
substring : (string nat nat -> string)

```

### Images

```

image=? : (image image -> boolean)
image? : (any -> boolean)

```

### Misc

```

=~ : (real real non-negative-real -> boolean)
eof : eof
eof-object? : (any -> boolean)
eq? : (any any -> boolean)
equal? : (any any -> boolean)
equal~? : (any any non-negative-real -> boolean)
eqv? : (any any -> boolean)
error : (symbol string -> void)
exit : (-> void)
identity : (any -> any)
struct? : (any -> boolean)

```

### Higher-Order Functions

```

andmap : ((X -> boolean) (listof X) -> boolean)
apply : ((X-1 ... X-N -> Y)
         X-1
         ...
         X-i
         (list X-i+1 ... X-N)
         ->
         Y)
argmax : ((X -> real) (listof X) -> X)
argmin : ((X -> real) (listof X) -> X)
build-list : (nat (nat -> X) -> (listof X))
build-string : (nat (nat -> char) -> string)
compose : ((Y-1 -> Z)
           ...
           (Y-N -> Y-N-1)
           (X-1 ... X-N -> Y-N)
           ->
           (X-1 ... X-N -> Z))
filter : ((X -> boolean) (listof X) -> (listof X))
foldl : ((X Y -> Y) Y (listof X) -> Y)
foldr : ((X Y -> Y) Y (listof X) -> Y)
for-each : ((any ... -> any) (listof any) ... -> void)
map : ((X ... -> Z) (listof X) ... -> (listof Z))
memf : ((X -> boolean)
        (listof X)
        ->
        (union false (listof X)))

```

```
ormap : ((X -> boolean) (listof X) -> boolean)
procedure? : (any -> boolean)
quicksort : ((listof X) (X X -> boolean) -> (listof X))
sort : ((listof X) (X X -> boolean) -> (listof X))
```

### 3.1 define

---

```
(define (id id id ...) expr)
(define id expr)
(define id (lambda (id id ...) expr))
```

Besides working in `local`, definition forms are the same as Beginning's `define`.

---

`lambda`

As in Beginning, `lambda` keyword can only be used with `define` in the alternative function-definition syntax.

### 3.2 define-struct

---

```
(define-struct structid (fieldid ...))
```

Besides working in `local`, this form is the same as Beginning's `define-struct`.

### 3.3 local

---

```
(local [definition ...] expr)
```

Groups related definitions for use in `expr`. Each `definition` is evaluated in order, and finally the body `expr` is evaluated. Only the expressions within the `local` form (including the right-hand-sides of the `definitions` and the `expr`) may refer to the names defined by the `definitions`. If a name defined in the `local` form is the same as a top-level binding, the inner one “shadows” the outer one. That is, inside the `local` form, any references to that name refer to the inner one.

Since `local` is an expression and may occur anywhere an expression may occur, it introduces the notion of lexical scope. Expressions within the `local` may “escape” the scope of the `local`, but these expressions may still refer to the bindings established by the `local`.

### 3.4 letrec, let, and let\*

---

```
(letrec ([id expr-for-let] ...) expr)
```

Similar to `local`, but essentially omitting the `define` for each definition.

A *expr-for-let* can be either an expression for a constant definition or a lambda form for a function definition.

---

```
(let ([id expr-for-let] ...) expr)
```

Like `letrec`, but the defined *ids* can be used only in the last *expr*, not the *expr-for-lets* next to the *ids*.

---

```
(let* ([id expr-for-let] ...) expr)
```

Like `let`, but each *id* can be used in any subsequent *expr-for-let*, in addition to *expr*.

### 3.5 Function Calls

---

```
(id expr expr ...)
```

A function call in Intermediate is the same as a Beginning function call, except that it can also call locally defined functions or functions passed as arguments. That is, *id* can be a function defined in `local` or an argument name while in a function.

---

```
(#%app id expr expr ...)
```

A function call can be written with  `#%app`, though it's practically never written that way.

### 3.6 time

---

```
(time expr)
```

This form is used to measure the time taken to evaluate *expr*. After evaluating *expr*, Scheme prints out the time taken by the evaluation (including real time, time taken by the cpu, and the time spent collecting free memory) and returns the result of the expression.

### 3.7 Identifiers

---

`id`

An `id` refers to a defined constant (possibly local), defined function (possibly local), or argument within a function body. If no definition or argument matches the `id` name, an error is reported.

### 3.8 Primitive Operations

---

`prim-op`

The name of a primitive operation can be used as an expression. If it is passed to a function, then it can be used in a function call within the function's body.

---

`*` : (num num num ... -> num)

Purpose: to compute the product of all of the input numbers

---

`+` : (num num num ... -> num)

Purpose: to compute the sum of the input numbers

---

`-` : (num num ... -> num)

Purpose: to subtract the second (and following) number(s) from the first; negate the number if there is only one argument

---

`/` : (num num num ... -> num)

Purpose: to divide the first by the second (and all following) number(s); try `(/ 3 4)` and `(/ 3 2 2)` only the first number can be zero.

---

`<` : (real real real ... -> boolean)

Purpose: to compare real numbers for less-than

---



`<= : (real real real ... -> boolean)`

Purpose: to compare real numbers for less-than or equality

---

`= : (num num num ... -> boolean)`

Purpose: to compare numbers for equality

---

`> : (real real real ... -> boolean)`

Purpose: to compare real numbers for greater-than

---

`>= : (real real ... -> boolean)`

Purpose: to compare real numbers for greater-than or equality

---

`abs : (real -> real)`

Purpose: to compute the absolute value of a real number

---

`acos : (num -> num)`

Purpose: to compute the arccosine (inverse of cos) of a number

---

`add1 : (number -> number)`

Purpose: to compute a number one larger than a given number

---

`angle : (num -> real)`

Purpose: to extract the angle from a complex number

---

`asin : (num -> num)`

Purpose: to compute the arcsine (inverse of sin) of a number

---

`atan : (num -> num)`

Purpose: to compute the arctan (inverse of tan) of a number

---

`ceiling` : (real -> int)

Purpose: to determine the closest integer above a real number

---

`complex?` : (any -> boolean)

Purpose: to determine whether some value is complex

---

`conjugate` : (num -> num)

Purpose: to compute the conjugate of a complex number

---

`cos` : (num -> num)

Purpose: to compute the cosine of a number (radians)

---

`cosh` : (num -> num)

Purpose: to compute the hyperbolic cosine of a number

---

`current-seconds` : (-> int)

Purpose: to compute the current time in seconds elapsed (since a platform-specific starting date)

---

`denominator` : (rat -> int)

Purpose: to compute the denominator of a rational

---

`e` : real

Purpose: Euler's number

---

`even?` : (integer -> boolean)

Purpose: to determine if some value is even or not

---

`exact->inexact` : (num -> num)

Purpose: to convert an exact number to an inexact one

---

```
exact? : (num -> boolean)
```

Purpose: to determine whether some number is exact

---

```
exp : (num -> num)
```

Purpose: to compute e raised to a number

---

```
expt : (num num -> num)
```

Purpose: to compute the power of the first to the second number

---

```
floor : (real -> int)
```

Purpose: to determine the closest integer below a real number

---

```
gcd : (int int ... -> int)
```

Purpose: to compute the greatest common divisor

---

```
imag-part : (num -> real)
```

Purpose: to extract the imaginary part from a complex number

---

```
inexact->exact : (num -> num)
```

Purpose: to approximate an inexact number by an exact one

---

```
inexact? : (num -> boolean)
```

Purpose: to determine whether some number is inexact

---

```
integer->char : (int -> char)
```

Purpose: to lookup the character that corresponds to the given integer in the ASCII table (if any)

---

`integer?` : (any -> boolean)

Purpose: to determine whether some value is an integer (exact or inexact)

---

`lcm` : (int int ... -> int)

Purpose: to compute the least common multiple of two integers

---

`log` : (num -> num)

Purpose: to compute the base-e logarithm of a number

---

`magnitude` : (num -> real)

Purpose: to determine the magnitude of a complex number

---

`make-polar` : (real real -> num)

Purpose: to create a complex from a magnitude and angle

---

`max` : (real real ... -> real)

Purpose: to determine the largest number

---

`min` : (real real ... -> real)

Purpose: to determine the smallest number

---

`modulo` : (int int -> int)

Purpose: to find the remainder of the division of the first number by the second; try (modulo 4 3) (modulo 4 -3)

---

`negative?` : (number -> boolean)

Purpose: to determine if some value is strictly smaller than zero

---

`number->string` : (num -> string)

Purpose: to convert a number to a string

---

```
number? : (any -> boolean)
```

Purpose: to determine whether some value is a number

---

```
numerator : (rat -> int)
```

Purpose: to compute the numerator of a rational

---

```
odd? : (integer -> boolean)
```

Purpose: to determine if some value is odd or not

---

```
pi : real
```

Purpose: the ratio of a circle's circumference to its diameter

---

```
positive? : (number -> boolean)
```

Purpose: to determine if some value is strictly larger than zero

---

```
quotient : (int int -> int)
```

Purpose: to divide the first integer into the second; try (quotient 3 4) and (quotient 4 3)

---

```
random : (int -> int)
```

Purpose: to generate a random natural number less than some given integer

---

```
rational? : (any -> boolean)
```

Purpose: to determine whether some value is a rational number

---

```
real-part : (num -> real)
```

Purpose: to extract the real part from a complex number

---

```
real? : (any -> boolean)
```

Purpose: to determine whether some value is a real number

---

```
remainder : (int int -> int)
```

Purpose: to determine the remainder of dividing the first by the second integer

---

```
round : (real -> int)
```

Purpose: to round a real number to an integer (rounds to even to break ties)

---

```
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
```

Purpose: to compute the sign of a real number

---

```
sin : (num -> num)
```

Purpose: to compute the sine of a number (radians)

---

```
sinh : (num -> num)
```

Purpose: to compute the hyperbolic sine of a number

---

```
sqr : (num -> num)
```

Purpose: to compute the square of a number

---

```
sqrt : (num -> num)
```

Purpose: to compute the square root of a number

---

```
sub1 : (number -> number)
```

Purpose: to compute a number one smaller than a given number

---

```
tan : (num -> num)
```

Purpose: to compute the tangent of a number (radians)

---

`zero? : (number -> boolean)`

Purpose: to determine if some value is zero or not

---

`boolean=? : (boolean boolean -> boolean)`

Purpose: to determine whether two booleans are equal

---

`boolean? : (any -> boolean)`

Purpose: to determine whether some value is a boolean

---

`false? : (any -> boolean)`

Purpose: to determine whether a value is false

---

`not : (boolean -> boolean)`

Purpose: to compute the negation of a boolean value

---

`symbol->string : (symbol -> string)`

Purpose: to convert a symbol to a string

---

`symbol=? : (symbol symbol -> boolean)`

Purpose: to determine whether two symbols are equal

---

`symbol? : (any -> boolean)`

Purpose: to determine whether some value is a symbol

---

`append : ((listof any)  
          (listof any)  
          (listof any)  
          ...  
          ->  
          (listof any))`

Purpose: to create a single list from several, by juxtaposition of the items

---

```
assq : (X
      (listof (cons X Y))
      ->
      (union false (cons X Y)))
```

Purpose: to determine whether some item is the first item of a pair in a list of pairs

---

```
caaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        W)
```

Purpose: to select the first item of the first list in the first list of a list

---

```
caadr : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
```

Purpose: to select the first item of the first list in a list

---

```
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
```

Purpose: to select the second item of the first list of a list

---

```
caddr : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```



Purpose: to select the third item of a non-empty list

---

```
cadr : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
car : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
         ->
         (listof Y))
```

Purpose: to select the rest of the first list in the rest of a list

---

```
cdar : ((cons (cons Z (listof Y)) (listof X))
        ->
        (listof Y))
```

Purpose: to select the rest of a non-empty list in a list

---

```
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         (listof Y))
```

Purpose: to select the rest of the rest of the first list of a list

---

```
cdddr : ((cons W (cons Z (cons Y (listof X))))
         ->
         (listof X))
```

Purpose: to select the rest of the rest of the rest of a list

---

```
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
```

Purpose: to select the rest of the rest of a list

---

```
cdr : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
cons : (X (listof X) -> (listof X))
```

Purpose: to construct a list

---

```
cons? : (any -> boolean)
```

Purpose: to determine whether some value is a constructed list

---

```
eighth : ((listof Y) -> Y)
```

Purpose: to select the eighth item of a non-empty list

---

```
empty? : (any -> boolean)
```

Purpose: to determine whether some value is the empty list

---

```
fifth : ((listof Y) -> Y)
```

Purpose: to select the fifth item of a non-empty list

---

```
first : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
fourth : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

`length` : ((listof any) -> number)

Purpose: to compute the number of items on a list

---

`list` : (any ... -> (listof any))

Purpose: to construct a list of its arguments

---

`list*` : (any ... (listof any) -> (listof any))

Purpose: to construct a list by adding multiple items to a list

---

`list-ref` : ((listof X) natural-number -> X)

Purpose: to extract the indexed item from the list

---

`member` : (any (listof any) -> boolean)

Purpose: to determine whether some value is on the list (comparing values with equal?)

---

`memq` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on some list (comparing values with eq?)

---

`memv` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on the list (comparing values with eqv?)

---

`null` : empty

Purpose: the empty list

---

`null?` : (any -> boolean)

Purpose: to determine whether some value is the empty list

---

`pair?` : (any -> boolean)

Purpose: to determine whether some value is a constructed list

---

```
rest : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
reverse : ((listof any) -> list)
```

Purpose: to create a reversed version of a list

---

```
second : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
seventh : ((listof Y) -> Y)
```

Purpose: to select the seventh item of a non-empty list

---

```
sixth : ((listof Y) -> Y)
```

Purpose: to select the sixth item of a non-empty list

---

```
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
make-posn : (number number -> posn)
```

Purpose: to construct a posn

---

```
posn-x : (posn -> number)
```

Purpose: to extract the x component of a posn

---

```
posn-y : (posn -> number)
```

Purpose: to extract the y component of a posn

---

```
posn? : (anything -> boolean)
```

Purpose: to determine if its input is a posn

---

`char->integer` : (char -> integer)

Purpose: to lookup the number that corresponds to the given character in the ASCII table (if any)

---

`char-alphabetic?` : (char -> boolean)

Purpose: to determine whether a character represents an alphabetic character

---

`char-ci<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it) in a case-insensitive manner

---

`char-ci<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another in a case-insensitive manner

---

`char-ci=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal in a case-insensitive manner

---

`char-ci>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it) in a case-insensitive manner

---

`char-ci>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another in a case-insensitive manner

---

`char-downcase` : (char -> char)

Purpose: to determine the equivalent lower-case character

---

`char-lower-case?` : (char -> boolean)

Purpose: to determine whether a character is a lower-case character

---

```
char-numeric? : (char -> boolean)
```

Purpose: to determine whether a character represents a digit

---

```
char-upcase : (char -> char)
```

Purpose: to determine the equivalent upper-case character

---

```
char-upper-case? : (char -> boolean)
```

Purpose: to determine whether a character is an upper-case character

---

```
char-whitespace? : (char -> boolean)
```

Purpose: to determine whether a character represents space

---

```
char<=? : (char char char ... -> boolean)
```

Purpose: to determine whether a character precedes another (or is equal to it)

---

```
char<? : (char char char ... -> boolean)
```

Purpose: to determine whether a character precedes another

---

```
char=? : (char char char ... -> boolean)
```

Purpose: to determine whether two characters are equal

---

```
char>=? : (char char char ... -> boolean)
```

Purpose: to determine whether a character succeeds another (or is equal to it)

---

```
char>? : (char char char ... -> boolean)
```

Purpose: to determine whether a character succeeds another

---

`char?` : (any -> boolean)

Purpose: to determine whether a value is a character

---

`format` : (string any ... -> string)

Purpose: to format a string, possibly embedding values

---

`list->string` : ((listof char) -> string)

Purpose: to convert a list of characters into a string

---

`make-string` : (nat char -> string)

Purpose: to produce a string of given length from a single given character

---

`string` : (char ... -> string)

Purpose: (string c1 c2 ...) builds a string

---

`string->list` : (string -> (listof char))

Purpose: to convert a string into a list of characters

---

`string->number` : (string -> (union number false))

Purpose: to convert a string into a number, produce false if impossible

---

`string->symbol` : (string -> symbol)

Purpose: to convert a string into a symbol

---

`string-append` : (string ... -> string)

Purpose: to juxtapose the characters of several strings

---

`string-ci<=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

in a case-insensitive manner

---

`string-ci<? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another in a case-insensitive manner

---

`string-ci=? : (string string string ... -> boolean)`

Purpose: to compare two strings character-wise in a case-insensitive manner

---

`string-ci>=? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it) in a case-insensitive manner

---

`string-ci>? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another in a case-insensitive manner

---

`string-copy : (string -> string)`

Purpose: to copy a string

---

`string-length : (string -> nat)`

Purpose: to determine the length of a string

---

`string-ref : (string nat -> char)`

Purpose: to extract the i-th character from a string

---

`string<=? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

---

`string<? : (string string string ... -> boolean)`



Purpose: to determine whether one string alphabetically precedes another

---

```
string=? : (string string string ... -> boolean)
```

Purpose: to compare two strings character-wise

---

```
string>=? : (string string string ... -> boolean)
```

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it)

---

```
string>? : (string string string ... -> boolean)
```

Purpose: to determine whether one string alphabetically succeeds another

---

```
string? : (any -> boolean)
```

Purpose: to determine whether a value is a string

---

```
substring : (string nat nat -> string)
```

Purpose: to extract the substring starting at a 0-based index up to the second 0-based index (exclusive)

---

```
image=? : (image image -> boolean)
```

Purpose: to determine whether two images are equal

---

```
image? : (any -> boolean)
```

Purpose: to determine whether a value is an image

---

```
=~ : (real real non-negative-real -> boolean)
```

Purpose: to check whether two real numbers are within some amount (the third argument) of either other

---

```
eof : eof
```

Purpose: the end-of-file value

---

`eof-object?` : (any -> boolean)

Purpose: to determine whether some value is the end-of-file value

---

`eq?` : (any any -> boolean)

Purpose: to compare two values

---

`equal?` : (any any -> boolean)

Purpose: to determine whether two values are structurally equal

---

`equal~?` : (any any non-negative-real -> boolean)

Purpose: to compare like `equal?` on the first two arguments, except using `=~` in the case of real numbers

---

`eqv?` : (any any -> boolean)

Purpose: to compare two values

---

`error` : (symbol string -> void)

Purpose: to signal an error

---

`exit` : (-> void)

Purpose: to exit the running program

---

`identity` : (any -> any)

Purpose: to return the argument unchanged

---

`struct?` : (any -> boolean)

Purpose: to determine whether some value is a structure

---

`andmap` : ((X -> boolean) (listof X) -> boolean)

Purpose:  $(\text{andmap } p \text{ (list } x-1 \dots x-n)) = (\text{and } (p \ x-1) \text{ (and } \dots \text{ (p } x-n)))$

---

```
apply : ((X-1 ... X-N -> Y)
         X-1
         ...
         X-i
         (list X-i+1 ... X-N)
         ->
         Y)
```

Purpose: to apply a function using items from a list as the arguments

---

```
argmax : ((X -> real) (listof X) -> X)
```

Purpose: to find the (first) element of the list that minimizes the output of the function

---

```
argmin : ((X -> real) (listof X) -> X)
```

Purpose: to find the (first) element of the list that minimizes the output of the function

---

```
build-list : (nat (nat -> X) -> (listof X))
```

Purpose:  $(\text{build-list } n \ f) = (\text{list } (f \ 0) \dots (f \ (- \ n \ 1)))$

---

```
build-string : (nat (nat -> char) -> string)
```

Purpose:  $(\text{build-string } n \ f) = (\text{string } (f \ 0) \dots (f \ (- \ n \ 1)))$

---

```
compose : ((Y-1 -> Z)
           ...
           (Y-N -> Y-N-1)
           (X-1 ... X-N -> Y-N)
           ->
           (X-1 ... X-N -> Z))
```

Purpose: to compose a sequence of procedures into a single procedure

---

```
filter : ((X -> boolean) (listof X) -> (listof X))
```

Purpose: to construct a list from all those items on a list for which the predicate holds

---

`foldl` : ((X Y -> Y) Y (listof X) -> Y)

Purpose: (foldl f base (list x-1 ... x-n)) = (f x-n ... (f x-1 base))

---

`foldr` : ((X Y -> Y) Y (listof X) -> Y)

Purpose: (foldr f base (list x-1 ... x-n)) = (f x-1 ... (f x-n base))

---

`for-each` : ((any ... -> any) (listof any) ... -> void)

Purpose: to apply a function to each item on one or more lists for effect only

---

`map` : ((X ... -> Z) (listof X) ... -> (listof Z))

Purpose: to construct a new list by applying a function to each item on one or more existing lists

---

`memf` : ((X -> boolean)  
         (listof X)  
         ->  
         (union false (listof X)))

Purpose: to determine whether the first argument produces true for some value in the second argument

---

`ormap` : ((X -> boolean) (listof X) -> boolean)

Purpose: (ormap p (list x-1 ... x-n)) = (or (p x-1) (or ... (p x-n)))

---

`procedure?` : (any -> boolean)

Purpose: to determine if a value is a procedure

---

`quicksort` : ((listof X) (X X -> boolean) -> (listof X))

Purpose: to construct a list from all items on a list in an order according to a predicate

---

`sort` : ((listof X) (X X -> boolean) -> (listof X))

Purpose: to construct a list from all items on a list in an order according to a predicate

### 3.9 Unchanged Forms

---

```
(cond [expr expr] ... [expr expr])  
else
```

The same as Beginning's cond.

---

```
(if expr expr expr)
```

The same as Beginning's if.

---

```
(and expr expr expr ...)  
(or expr expr expr ...)
```

The same as Beginning's and and or.

---

```
(check-expect expr expr)  
(check-within expr expr expr)  
(check-error expr expr)
```

The same as Beginning's check-expect, etc.

---

```
empty : empty?  
true : boolean?  
false : boolean?
```

Constants for the empty list, true, and false.

---

```
(require string)
```

The same as Beginning's require.

## 4 Intermediate Student with Lambda

```
program = def-or-expr ...

def-or-expr = definition
            | expr
            | test-case
            | library-require

definition = (define (id id id ...) expr)
            | (define id expr)
            | (define-struct id (id ...))

expr = (lambda (id id ...) expr)
      | (local [definition ...] expr)
      | (letrec ([id expr] ...) expr)
      | (let ([id expr] ...) expr)
      | (let* ([id expr] ...) expr)
      | (expr expr expr ...) ; function call
      | (cond [expr expr] ... [expr expr])
      | (cond [expr expr] ... [else expr])
      | (if expr expr expr)
      | (and expr expr expr ...)
      | (or expr expr expr ...)
      | (time expr)
      | empty
      | id ; identifier
      | prim-op ; primitive operation
      | 'id
      | 'quoted ; quoted value
      | 'quasiquoted ; quasiquote
      | number
      | true
      | false
      | string
      | character

quoted = id
        | number
        | string
        | character
        | (quoted ...)
        | 'quoted
        | 'quoted
        | ,quoted
```

```

| ,@quoted

quasiquoted = id
| number
| string
| character
| (quasiquoted ...)
| 'quasiquoted
| `quasiquoted
| ,expr
| ,@expr

test-case = (check-expect expr expr)
| (check-within expr expr expr)
| (check-error expr expr)

library-require = (require string)
| (require (lib string string ...))
| (require (planet string package))

package = (string string number number)

```

An *id* is a sequence of characters not including a space or one of the following:

```
" , ' ( ) [ ] { } | ; #
```

A *number* is a number such as 123, 3/2, or 5.5.

A *string* is enclosed by a pair of `"`. Unlike symbols, strings may be split into characters and manipulated by a variety of primitive functions. For example, "abcdef", "This is a string", and "This is a string with \" inside" are all strings.

A *character* begins with `#\` and has the name of the character. For example, `#\a`, `#\b`, and `#\space` are characters.

A *prim-op* is one of:

**Numbers: Integers, Rationals, Reals, Complex, Exacts, Inexacts**

```

* : (num num num ... -> num)
+ : (num num num ... -> num)
- : (num num ... -> num)
/ : (num num num ... -> num)
< : (real real real ... -> boolean)
<= : (real real real ... -> boolean)
= : (num num num ... -> boolean)
> : (real real real ... -> boolean)
>= : (real real ... -> boolean)
abs : (real -> real)

```

```

acos : (num -> num)
add1 : (number -> number)
angle : (num -> real)
asin : (num -> num)
atan : (num -> num)
ceiling : (real -> int)
complex? : (any -> boolean)
conjugate : (num -> num)
cos : (num -> num)
cosh : (num -> num)
current-seconds : (-> int)
denominator : (rat -> int)
e : real
even? : (integer -> boolean)
exact->inexact : (num -> num)
exact? : (num -> boolean)
exp : (num -> num)
expt : (num num -> num)
floor : (real -> int)
gcd : (int int ... -> int)
imag-part : (num -> real)
inexact->exact : (num -> num)
inexact? : (num -> boolean)
integer->char : (int -> char)
integer? : (any -> boolean)
lcm : (int int ... -> int)
log : (num -> num)
magnitude : (num -> real)
make-polar : (real real -> num)
max : (real real ... -> real)
min : (real real ... -> real)
modulo : (int int -> int)
negative? : (number -> boolean)
number->string : (num -> string)
number? : (any -> boolean)
numerator : (rat -> int)
odd? : (integer -> boolean)
pi : real
positive? : (number -> boolean)
quotient : (int int -> int)
random : (int -> int)
rational? : (any -> boolean)
real-part : (num -> real)
real? : (any -> boolean)
remainder : (int int -> int)
round : (real -> int)

```



```

sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
sin : (num -> num)
sinh : (num -> num)
sqr : (num -> num)
sqrt : (num -> num)
sub1 : (number -> number)
tan : (num -> num)
zero? : (number -> boolean)

```

### Booleans

```

boolean=? : (boolean boolean -> boolean)
boolean? : (any -> boolean)
false? : (any -> boolean)
not : (boolean -> boolean)

```

### Symbols

```

symbol->string : (symbol -> string)
symbol=? : (symbol symbol -> boolean)
symbol? : (any -> boolean)

```

### Lists

```

append : ((listof any)
          (listof any)
          (listof any)
          ...
          ->
          (listof any))
assq : (X
        (listof (cons X Y))
        ->
        (union false (cons X Y)))
caaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
        ->
        W)
caadr : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
        ->
        (listof Z))
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
caddr : ((listof Y) -> Y)
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
cadr : ((cons Z (cons Y (listof X))) -> Y)
car : ((cons Y (listof X)) -> Y)

```

```

cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         (listof Z))
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
         ->
         (listof Y))
cdar : ((cons (cons Z (listof Y)) (listof X))
        ->
        (listof Y))
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
         ->
         (listof Y))
cddddr : ((cons W (cons Z (cons Y (listof X))))
          ->
          (listof X))
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
cdr : ((cons Y (listof X)) -> (listof X))
cons : (X (listof X) -> (listof X))
cons? : (any -> boolean)
eighth : ((listof Y) -> Y)
empty? : (any -> boolean)
fifth : ((listof Y) -> Y)
first : ((cons Y (listof X)) -> Y)
fourth : ((listof Y) -> Y)
length : ((listof any) -> number)
list : (any ... -> (listof any))
list* : (any ... (listof any) -> (listof any))
list-ref : ((listof X) natural-number -> X)
member : (any (listof any) -> boolean)
memq : (any (listof any) -> (union false list))
memv : (any (listof any) -> (union false list))
null : empty
null? : (any -> boolean)
pair? : (any -> boolean)
rest : ((cons Y (listof X)) -> (listof X))
reverse : ((listof any) -> list)
second : ((cons Z (cons Y (listof X))) -> Y)
seventh : ((listof Y) -> Y)
sixth : ((listof Y) -> Y)
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)

```

### Posns

```

make-posn : (number number -> posn)
posn-x : (posn -> number)
posn-y : (posn -> number)

```

posn? : (anything -> boolean)

### Characters

char->integer : (char -> integer)  
char-alphabetic? : (char -> boolean)  
char-ci<=? : (char char char ... -> boolean)  
char-ci<? : (char char char ... -> boolean)  
char-ci=? : (char char char ... -> boolean)  
char-ci>=? : (char char char ... -> boolean)  
char-ci>? : (char char char ... -> boolean)  
char-downcase : (char -> char)  
char-lower-case? : (char -> boolean)  
char-numeric? : (char -> boolean)  
char-upcase : (char -> char)  
char-upper-case? : (char -> boolean)  
char-whitespace? : (char -> boolean)  
char<=? : (char char char ... -> boolean)  
char<? : (char char char ... -> boolean)  
char=? : (char char char ... -> boolean)  
char>=? : (char char char ... -> boolean)  
char>? : (char char char ... -> boolean)  
char? : (any -> boolean)

### Strings

format : (string any ... -> string)  
list->string : ((listof char) -> string)  
make-string : (nat char -> string)  
string : (char ... -> string)  
string->list : (string -> (listof char))  
string->number : (string -> (union number false))  
string->symbol : (string -> symbol)  
string-append : (string ... -> string)  
string-ci<=? : (string string string ... -> boolean)  
string-ci<? : (string string string ... -> boolean)  
string-ci=? : (string string string ... -> boolean)  
string-ci>=? : (string string string ... -> boolean)  
string-ci>? : (string string string ... -> boolean)  
string-copy : (string -> string)  
string-length : (string -> nat)  
string-ref : (string nat -> char)  
string<=? : (string string string ... -> boolean)  
string<? : (string string string ... -> boolean)  
string=? : (string string string ... -> boolean)  
string>=? : (string string string ... -> boolean)  
string>? : (string string string ... -> boolean)  
string? : (any -> boolean)  
substring : (string nat nat -> string)

### Images

```
image=? : (image image -> boolean)
image? : (any -> boolean)
```

### Misc

```
=~ : (real real non-negative-real -> boolean)
eof : eof
eof-object? : (any -> boolean)
eq? : (any any -> boolean)
equal? : (any any -> boolean)
equal~? : (any any non-negative-real -> boolean)
eqv? : (any any -> boolean)
error : (symbol string -> void)
exit : (-> void)
identity : (any -> any)
struct? : (any -> boolean)
```

### Higher-Order Functions

```
andmap : ((X -> boolean) (listof X) -> boolean)
apply : ((X-1 ... X-N -> Y)
         X-1
         ...
         X-i
         (list X-i+1 ... X-N)
         ->
         Y)
argmax : ((X -> real) (listof X) -> X)
argmin : ((X -> real) (listof X) -> X)
build-list : (nat (nat -> X) -> (listof X))
build-string : (nat (nat -> char) -> string)
compose : ((Y-1 -> Z)
           ...
           (Y-N -> Y-N-1)
           (X-1 ... X-N -> Y-N)
           ->
           (X-1 ... X-N -> Z))
filter : ((X -> boolean) (listof X) -> (listof X))
foldl : ((X Y -> Y) Y (listof X) -> Y)
foldr : ((X Y -> Y) Y (listof X) -> Y)
for-each : ((any ... -> any) (listof any) ... -> void)
map : ((X ... -> Z) (listof X) ... -> (listof Z))
memf : ((X -> boolean)
        (listof X)
        ->
        (union false (listof X)))
ormap : ((X -> boolean) (listof X) -> boolean)
procedure? : (any -> boolean)
quicksort : ((listof X) (X X -> boolean) -> (listof X))
sort : ((listof X) (X X -> boolean) -> (listof X))
```

## 4.1 define

---

```
(define (id id id ...) expr)
(define id expr)
```

The same as Intermediate's `define`. No special case is needed for `lambda`, since a `lambda` form is an expression.

## 4.2 lambda

---

```
(lambda (id id ...) expr)
```

Creates a function that takes as many arguments as given *ids*, and whose body is *expr*.

## 4.3 Function Calls

---

```
(expr expr expr ...)
```

Like a Beginning function call, except that the function position can be an arbitrary expression—perhaps a `lambda` expression or a *prim-op*.

---

```
(#%app expr expr expr ...)
```

A function call can be written with `#%app`, though it's practically never written that way.

## 4.4 Primitive Operation Names

---

```
prim-op
```

The name of a primitive operation can be used as an expression. It produces a function version of the operation.

---

```
* : (num num num ... -> num)
```

Purpose: to compute the product of all of the input numbers

---

`+ : (num num num ... -> num)`

Purpose: to compute the sum of the input numbers

---

`- : (num num ... -> num)`

Purpose: to subtract the second (and following) number(s) from the first; negate the number if there is only one argument

---

`/ : (num num num ... -> num)`

Purpose: to divide the first by the second (and all following) number(s); try `(/ 3 4)` and `(/ 3 2)` only the first number can be zero.

---

`< : (real real real ... -> boolean)`

Purpose: to compare real numbers for less-than

---

`<= : (real real real ... -> boolean)`

Purpose: to compare real numbers for less-than or equality

---

`= : (num num num ... -> boolean)`

Purpose: to compare numbers for equality

---

`> : (real real real ... -> boolean)`

Purpose: to compare real numbers for greater-than

---

`>= : (real real ... -> boolean)`

Purpose: to compare real numbers for greater-than or equality

---

`abs : (real -> real)`

Purpose: to compute the absolute value of a real number

---

`acos` : (num -> num)

Purpose: to compute the arccosine (inverse of cos) of a number

---

`add1` : (number -> number)

Purpose: to compute a number one larger than a given number

---

`angle` : (num -> real)

Purpose: to extract the angle from a complex number

---

`asin` : (num -> num)

Purpose: to compute the arcsine (inverse of sin) of a number

---

`atan` : (num -> num)

Purpose: to compute the arctan (inverse of tan) of a number

---

`ceiling` : (real -> int)

Purpose: to determine the closest integer above a real number

---

`complex?` : (any -> boolean)

Purpose: to determine whether some value is complex

---

`conjugate` : (num -> num)

Purpose: to compute the conjugate of a complex number

---

`cos` : (num -> num)

Purpose: to compute the cosine of a number (radians)

---

`cosh` : (num -> num)

Purpose: to compute the hyperbolic cosine of a number

---

`current-seconds` : (`-> int`)

Purpose: to compute the current time in seconds elapsed (since a platform-specific starting date)

---

`denominator` : (`rat -> int`)

Purpose: to compute the denominator of a rational

---

`e` : `real`

Purpose: Euler's number

---

`even?` : (`integer -> boolean`)

Purpose: to determine if some value is even or not

---

`exact->inexact` : (`num -> num`)

Purpose: to convert an exact number to an inexact one

---

`exact?` : (`num -> boolean`)

Purpose: to determine whether some number is exact

---

`exp` : (`num -> num`)

Purpose: to compute e raised to a number

---

`expt` : (`num num -> num`)

Purpose: to compute the power of the first to the second number

---

`floor` : (`real -> int`)

Purpose: to determine the closest integer below a real number

---

`gcd` : (`int int ... -> int`)



Purpose: to compute the greatest common divisor

---

`imag-part` : (num -> real)

Purpose: to extract the imaginary part from a complex number

---

`inexact->exact` : (num -> num)

Purpose: to approximate an inexact number by an exact one

---

`inexact?` : (num -> boolean)

Purpose: to determine whether some number is inexact

---

`integer->char` : (int -> char)

Purpose: to lookup the character that corresponds to the given integer in the ASCII table (if any)

---

`integer?` : (any -> boolean)

Purpose: to determine whether some value is an integer (exact or inexact)

---

`lcm` : (int int ... -> int)

Purpose: to compute the least common multiple of two integers

---

`log` : (num -> num)

Purpose: to compute the base-e logarithm of a number

---

`magnitude` : (num -> real)

Purpose: to determine the magnitude of a complex number

---

`make-polar` : (real real -> num)

Purpose: to create a complex from a magnitude and angle

---

`max : (real real ... -> real)`

Purpose: to determine the largest number

---

`min : (real real ... -> real)`

Purpose: to determine the smallest number

---

`modulo : (int int -> int)`

Purpose: to find the remainder of the division of the first number by the second; try (modulo 4 3) (modulo 4 -3)

---

`negative? : (number -> boolean)`

Purpose: to determine if some value is strictly smaller than zero

---

`number->string : (num -> string)`

Purpose: to convert a number to a string

---

`number? : (any -> boolean)`

Purpose: to determine whether some value is a number

---

`numerator : (rat -> int)`

Purpose: to compute the numerator of a rational

---

`odd? : (integer -> boolean)`

Purpose: to determine if some value is odd or not

---

`pi : real`

Purpose: the ratio of a circle's circumference to its diameter

---

`positive? : (number -> boolean)`

Purpose: to determine if some value is strictly larger than zero

---

```
quotient : (int int -> int)
```

Purpose: to divide the first integer into the second; try (quotient 3 4) and (quotient 4 3)

---

```
random : (int -> int)
```

Purpose: to generate a random natural number less than some given integer

---

```
rational? : (any -> boolean)
```

Purpose: to determine whether some value is a rational number

---

```
real-part : (num -> real)
```

Purpose: to extract the real part from a complex number

---

```
real? : (any -> boolean)
```

Purpose: to determine whether some value is a real number

---

```
remainder : (int int -> int)
```

Purpose: to determine the remainder of dividing the first by the second integer

---

```
round : (real -> int)
```

Purpose: to round a real number to an integer (rounds to even to break ties)

---

```
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
```

Purpose: to compute the sign of a real number

---

```
sin : (num -> num)
```

Purpose: to compute the sine of a number (radians)

---

`sinh` : (num -> num)

Purpose: to compute the hyperbolic sine of a number

---

`sqr` : (num -> num)

Purpose: to compute the square of a number

---

`sqrt` : (num -> num)

Purpose: to compute the square root of a number

---

`sub1` : (number -> number)

Purpose: to compute a number one smaller than a given number

---

`tan` : (num -> num)

Purpose: to compute the tangent of a number (radians)

---

`zero?` : (number -> boolean)

Purpose: to determine if some value is zero or not

---

`boolean=?` : (boolean boolean -> boolean)

Purpose: to determine whether two booleans are equal

---

`boolean?` : (any -> boolean)

Purpose: to determine whether some value is a boolean

---

`false?` : (any -> boolean)

Purpose: to determine whether a value is false

---

`not` : (boolean -> boolean)

Purpose: to compute the negation of a boolean value

---

```
symbol->string : (symbol -> string)
```

Purpose: to convert a symbol to a string

---

```
symbol=? : (symbol symbol -> boolean)
```

Purpose: to determine whether two symbols are equal

---

```
symbol? : (any -> boolean)
```

Purpose: to determine whether some value is a symbol

---

```
append : ((listof any)
           (listof any)
           (listof any)
           ...
           ->
           (listof any))
```

Purpose: to create a single list from several, by juxtaposition of the items

---

```
assq : (X
        (listof (cons X Y))
        ->
        (union false (cons X Y)))
```

Purpose: to determine whether some item is the first item of a pair in a list of pairs

---

```
caaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
         ->
         W)
```

Purpose: to select the first item of the first list in the first list of a list

---

```
caadr : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
```

Purpose: to select the first item of the first list in a list

---

```
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
```

Purpose: to select the second item of the first list of a list

---

```
caddr : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
cadr : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
car : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
cdaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))  
        ->  
        (listof Y))
```

Purpose: to select the rest of the first list in the rest of a list

---

```
cdar : ((cons (cons Z (listof Y)) (listof X))  
        ->  
        (listof Y))
```

Purpose: to select the rest of a non-empty list in a list

---

```
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))  
        ->  
        (listof Y))
```

Purpose: to select the rest of the rest of the first list of a list

---

```
cdddr : ((cons W (cons Z (cons Y (listof X))))  
        ->  
        (listof X))
```

Purpose: to select the rest of the rest of the rest of a list

---

```
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
```

Purpose: to select the rest of the rest of a list

---

```
cdr : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
cons : (X (listof X) -> (listof X))
```

Purpose: to construct a list

---

```
cons? : (any -> boolean)
```

Purpose: to determine whether some value is a constructed list

---

```
eighth : ((listof Y) -> Y)
```

Purpose: to select the eighth item of a non-empty list

---

```
empty? : (any -> boolean)
```

Purpose: to determine whether some value is the empty list

---

```
fifth : ((listof Y) -> Y)
```

Purpose: to select the fifth item of a non-empty list

---

```
first : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
fourth : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
length : ((listof any) -> number)
```

Purpose: to compute the number of items on a list

---

```
list : (any ... -> (listof any))
```

Purpose: to construct a list of its arguments

---

```
list* : (any ... (listof any) -> (listof any))
```

Purpose: to construct a list by adding multiple items to a list

---

```
list-ref : ((listof X) natural-number -> X)
```

Purpose: to extract the indexed item from the list

---



`member` : (any (listof any) -> boolean)

Purpose: to determine whether some value is on the list (comparing values with equal?)

---

`memq` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on some list (comparing values with eq?)

---

`memv` : (any (listof any) -> (union false list))

Purpose: to determine whether some value is on the list (comparing values with eqv?)

---

`null` : empty

Purpose: the empty list

---

`null?` : (any -> boolean)

Purpose: to determine whether some value is the empty list

---

`pair?` : (any -> boolean)

Purpose: to determine whether some value is a constructed list

---

`rest` : ((cons Y (listof X)) -> (listof X))

Purpose: to select the rest of a non-empty list

---

`reverse` : ((listof any) -> list)

Purpose: to create a reversed version of a list

---

`second` : ((cons Z (cons Y (listof X))) -> Y)

Purpose: to select the second item of a non-empty list

---

`seventh` : ((listof Y) -> Y)

Purpose: to select the seventh item of a non-empty list

---

```
sixth : ((listof Y) -> Y)
```

Purpose: to select the sixth item of a non-empty list

---

```
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
make-posn : (number number -> posn)
```

Purpose: to construct a posn

---

```
posn-x : (posn -> number)
```

Purpose: to extract the x component of a posn

---

```
posn-y : (posn -> number)
```

Purpose: to extract the y component of a posn

---

```
posn? : (anything -> boolean)
```

Purpose: to determine if its input is a posn

---

```
char->integer : (char -> integer)
```

Purpose: to lookup the number that corresponds to the given character in the ASCII table (if any)

---

```
char-alphabetic? : (char -> boolean)
```

Purpose: to determine whether a character represents an alphabetic character

---

```
char-ci<=? : (char char char ... -> boolean)
```

Purpose: to determine whether a character precedes another (or is equal to it) in a case-insensitive manner

---

`char-ci<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another in a case-insensitive manner

---

`char-ci=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal in a case-insensitive manner

---

`char-ci>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it) in a case-insensitive manner

---

`char-ci>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another in a case-insensitive manner

---

`char-downcase` : (char -> char)

Purpose: to determine the equivalent lower-case character

---

`char-lower-case?` : (char -> boolean)

Purpose: to determine whether a character is a lower-case character

---

`char-numeric?` : (char -> boolean)

Purpose: to determine whether a character represents a digit

---

`char-upcase` : (char -> char)

Purpose: to determine the equivalent upper-case character

---

`char-upper-case?` : (char -> boolean)

Purpose: to determine whether a character is an upper-case character

---

`char-whitespace?` : (char -> boolean)

Purpose: to determine whether a character represents space

---

```
char<=? : (char char char ... -> boolean)
```

Purpose: to determine whether a character precedes another (or is equal to it)

---

```
char<? : (char char char ... -> boolean)
```

Purpose: to determine whether a character precedes another

---

```
char=? : (char char char ... -> boolean)
```

Purpose: to determine whether two characters are equal

---

```
char>=? : (char char char ... -> boolean)
```

Purpose: to determine whether a character succeeds another (or is equal to it)

---

```
char>? : (char char char ... -> boolean)
```

Purpose: to determine whether a character succeeds another

---

```
char? : (any -> boolean)
```

Purpose: to determine whether a value is a character

---

```
format : (string any ... -> string)
```

Purpose: to format a string, possibly embedding values

---

```
list->string : ((listof char) -> string)
```

Purpose: to convert a list of characters into a string

---

```
make-string : (nat char -> string)
```

Purpose: to produce a string of given length from a single given character

---

`string` : (char ... -> string)

Purpose: (string c1 c2 ...) builds a string

---

`string->list` : (string -> (listof char))

Purpose: to convert a string into a list of characters

---

`string->number` : (string -> (union number false))

Purpose: to convert a string into a number, produce false if impossible

---

`string->symbol` : (string -> symbol)

Purpose: to convert a string into a symbol

---

`string-append` : (string ... -> string)

Purpose: to juxtapose the characters of several strings

---

`string-ci<=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another (or is equal to it) in a case-insensitive manner

---

`string-ci<?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another in a case-insensitive manner

---

`string-ci=?` : (string string string ... -> boolean)

Purpose: to compare two strings character-wise in a case-insensitive manner

---

`string-ci>=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it) in a case-insensitive manner

---

`string-ci>? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another in a case-insensitive manner

---

`string-copy : (string -> string)`

Purpose: to copy a string

---

`string-length : (string -> nat)`

Purpose: to determine the length of a string

---

`string-ref : (string nat -> char)`

Purpose: to extract the i-th character from a string

---

`string<=? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

---

`string<? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically precedes another

---

`string=? : (string string string ... -> boolean)`

Purpose: to compare two strings character-wise

---

`string>=? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it)

---

`string>? : (string string string ... -> boolean)`

Purpose: to determine whether one string alphabetically succeeds another

---

`string? : (any -> boolean)`

Purpose: to determine whether a value is a string

---

```
substring : (string nat nat -> string)
```

Purpose: to extract the substring starting at a 0-based index up to the second 0-based index (exclusive)

---

```
image=? : (image image -> boolean)
```

Purpose: to determine whether two images are equal

---

```
image? : (any -> boolean)
```

Purpose: to determine whether a value is an image

---

```
=~ : (real real non-negative-real -> boolean)
```

Purpose: to check whether two real numbers are within some amount (the third argument) of either other

---

```
eof : eof
```

Purpose: the end-of-file value

---

```
eof-object? : (any -> boolean)
```

Purpose: to determine whether some value is the end-of-file value

---

```
eq? : (any any -> boolean)
```

Purpose: to compare two values

---

```
equal? : (any any -> boolean)
```

Purpose: to determine whether two values are structurally equal

---

```
equal~? : (any any non-negative-real -> boolean)
```

Purpose: to compare like equal? on the first two arguments, except using =~ in the case of

real numbers

---

`eqv?` : (any any -> boolean)

Purpose: to compare two values

---

`error` : (symbol string -> void)

Purpose: to signal an error

---

`exit` : (-> void)

Purpose: to exit the running program

---

`identity` : (any -> any)

Purpose: to return the argument unchanged

---

`struct?` : (any -> boolean)

Purpose: to determine whether some value is a structure

---

`andmap` : ((X -> boolean) (listof X) -> boolean)

Purpose: (andmap p (list x-1 ... x-n)) = (and (p x-1) (and ... (p x-n)))

---

`apply` : ((X-1 ... X-N -> Y)  
X-1  
...  
X-i  
(list X-i+1 ... X-N)  
->  
Y)

Purpose: to apply a function using items from a list as the arguments

---

`argmax` : ((X -> real) (listof X) -> X)

Purpose: to find the (first) element of the list that minimizes the output of the function



---

`argmin` : ((X -> real) (listof X) -> X)

Purpose: to find the (first) element of the list that minimizes the output of the function

---

`build-list` : (nat (nat -> X) -> (listof X))

Purpose: (build-list n f) = (list (f 0) ... (f (- n 1)))

---

`build-string` : (nat (nat -> char) -> string)

Purpose: (build-string n f) = (string (f 0) ... (f (- n 1)))

---

`compose` : ((Y-1 -> Z)  
...  
(Y-N -> Y-N-1)  
(X-1 ... X-N -> Y-N)  
->  
(X-1 ... X-N -> Z))

Purpose: to compose a sequence of procedures into a single procedure

---

`filter` : ((X -> boolean) (listof X) -> (listof X))

Purpose: to construct a list from all those items on a list for which the predicate holds

---

`foldl` : ((X Y -> Y) Y (listof X) -> Y)

Purpose: (foldl f base (list x-1 ... x-n)) = (f x-n ... (f x-1 base))

---

`foldr` : ((X Y -> Y) Y (listof X) -> Y)

Purpose: (foldr f base (list x-1 ... x-n)) = (f x-1 ... (f x-n base))

---

`for-each` : ((any ... -> any) (listof any) ... -> void)

Purpose: to apply a function to each item on one or more lists for effect only

---

`map` : ((X ... -> Z) (listof X) ... -> (listof Z))

Purpose: to construct a new list by applying a function to each item on one or more existing lists

---

```
memf : ((X -> boolean)
        (listof X)
        ->
        (union false (listof X)))
```

Purpose: to determine whether the first argument produces true for some value in the second argument

---

```
ormap : ((X -> boolean) (listof X) -> boolean)
```

Purpose: (ormap p (list x-1 ... x-n)) = (or (p x-1) (or ... (p x-n)))

---

```
procedure? : (any -> boolean)
```

Purpose: to determine if a value is a procedure

---

```
quicksort : ((listof X) (X X -> boolean) -> (listof X))
```

Purpose: to construct a list from all items on a list in an order according to a predicate

---

```
sort : ((listof X) (X X -> boolean) -> (listof X))
```

Purpose: to construct a list from all items on a list in an order according to a predicate

## 4.5 Unchanged Forms

---

```
(define-struct structid (fieldid ...))
```

The same as Intermediate's `define-struct`.

---

```
(local [definition ...] expr)
(letrec ([id expr-for-let] ...) expr)
(let ([id expr-for-let] ...) expr)
(let* ([id expr-for-let] ...) expr)
```

The same as Intermediate's `local`, `letrec`, `let`, and `let*`.

---

```
(cond [expr expr] ... [expr expr])  
else
```

The same as Beginning's cond.

---

```
(if expr expr expr)
```

The same as Beginning's if.

---

```
(and expr expr expr ...)  
(or expr expr expr ...)
```

The same as Beginning's and and or.

---

```
(time expr)
```

The same as Intermediate's time.

---

```
(check-expect expr expr)  
(check-within expr expr expr)  
(check-error expr expr)
```

The same as Beginning's check-expect, etc.

---

```
empty : empty?  
true : boolean?  
false : boolean?
```

Constants for the empty list, true, and false.

---

```
(require string)
```

The same as Beginning's require.

## 5 Advanced Student

```
program = def-or-expr ...

def-or-expr = definition
            | expr
            | test-case
            | library-require

definition = (define (id id id ...) expr)
            | (define id expr)
            | (define-struct id (id ...))

expr = (begin expr expr ...)
      | (begin0 expr expr ...)
      | (set! id expr)
      | (delay expr)
      | (lambda (id ...) expr)
      | (local [definition ...] expr)
      | (letrec ([id expr] ...) expr)
      | (shared ([id expr] ...) expr)
      | (let ([id expr] ...) expr)
      | (let id ([id expr] ...) expr)
      | (let* ([id expr] ...) expr)
      | (recur id ([id expr] ...) expr)
      | (expr expr ...) ; function call
      | (cond [expr expr] ... [expr expr])
      | (cond [expr expr] ... [else expr])
      | (case expr [(choice choice ...) expr] ...
          [(choice choice ...) expr])
      | (case expr [(choice choice ...) expr] ...
          [else expr])
      | (if expr expr expr)
      | (when expr expr)
      | (unless expr expr)
      | (and expr expr expr ...)
      | (or expr expr expr ...)
      | (time expr)
      | empty
      | id ; identifier
      | prim-op ; primitive operation
      | 'id
      | 'quoted ; quoted value
      | 'quasiquoted ; quasiquote
      | number
```

```

| true
| false
| string
| character

choice = id ; treated as a symbol
| number

quoted = id
| number
| string
| character
| (quoted ...)
| 'quoted
| 'quoted
| ,quoted
| ,@quoted

quasiquoted = id
| number
| string
| character
| (quasiquoted ...)
| 'quasiquoted
| 'quasiquoted
| ,expr
| ,@expr

test-case = (check-expect expr expr)
| (check-within expr expr expr)
| (check-error expr expr)

library-require = (require string)
| (require (lib string string ...))
| (require (planet string package))

package = (string string number number)

```

An *id* is a sequence of characters not including a space or one of the following:

```
" , ' ( ) [ ] { } | ; #
```

A *number* is a number such as 123, 3/2, or 5.5.

A *string* is enclosed by a pair of `"`. Unlike symbols, strings may be split into characters and manipulated by a variety of primitive functions. For example, "abcdef", "This is a

string", and "This is a string with \" inside" are all strings.

A *character* begins with #\ and has the name of the character. For example, #\a, #\b, and #\space are characters.

A *prim-op* is one of:

**Numbers: Integers, Rationals, Reals, Complex, Exacts, Inexacts**

```
* : (num num num ... -> num)
+ : (num num num ... -> num)
- : (num num ... -> num)
/ : (num num num ... -> num)
< : (real real real ... -> boolean)
<= : (real real real ... -> boolean)
= : (num num num ... -> boolean)
> : (real real real ... -> boolean)
>= : (real real ... -> boolean)
abs : (real -> real)
acos : (num -> num)
add1 : (number -> number)
angle : (num -> real)
asin : (num -> num)
atan : (num -> num)
ceiling : (real -> int)
complex? : (any -> boolean)
conjugate : (num -> num)
cos : (num -> num)
cosh : (num -> num)
current-seconds : (-> int)
denominator : (rat -> int)
e : real
even? : (integer -> boolean)
exact->inexact : (num -> num)
exact? : (num -> boolean)
exp : (num -> num)
expt : (num num -> num)
floor : (real -> int)
gcd : (int int ... -> int)
imag-part : (num -> real)
inexact->exact : (num -> num)
inexact? : (num -> boolean)
integer->char : (int -> char)
integer? : (any -> boolean)
lcm : (int int ... -> int)
log : (num -> num)
magnitude : (num -> real)
make-polar : (real real -> num)
```

```

max : (real real ... -> real)
min : (real real ... -> real)
modulo : (int int -> int)
negative? : (number -> boolean)
number->string : (num -> string)
number? : (any -> boolean)
numerator : (rat -> int)
odd? : (integer -> boolean)
pi : real
positive? : (number -> boolean)
quotient : (int int -> int)
random : (int -> int)
rational? : (any -> boolean)
real-part : (num -> real)
real? : (any -> boolean)
remainder : (int int -> int)
round : (real -> int)
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
sin : (num -> num)
sinh : (num -> num)
sqr : (num -> num)
sqrt : (num -> num)
sub1 : (number -> number)
tan : (num -> num)
zero? : (number -> boolean)

```

#### Booleans

```

boolean=? : (boolean boolean -> boolean)
boolean? : (any -> boolean)
false? : (any -> boolean)
not : (boolean -> boolean)

```

#### Symbols

```

symbol->string : (symbol -> string)
symbol=? : (symbol symbol -> boolean)
symbol? : (any -> boolean)

```

#### Lists

```

append : ((listof any) ... -> (listof any))
assq : (X
      (listof (cons X Y))
      ->
      (union false (cons X Y)))
caaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
      ->
      W)

```

```

caadr : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
caddr : ((listof Y) -> Y)
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
cadr : ((cons Z (cons Y (listof X))) -> Y)
car : ((cons Y (listof X)) -> Y)
cdaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
        ->
        (listof Y))
cdar : ((cons (cons Z (listof Y)) (listof X))
        ->
        (listof Y))
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        (listof Y))
cddddr : ((cons W (cons Z (cons Y (listof X))))
        ->
        (listof X))
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
cdr : ((cons Y (listof X)) -> (listof X))
cons : (X (listof X) -> (listof X))
cons? : (any -> boolean)
eighth : ((listof Y) -> Y)
empty? : (any -> boolean)
fifth : ((listof Y) -> Y)
first : ((cons Y (listof X)) -> Y)
fourth : ((listof Y) -> Y)
length : ((listof any) -> number)
list : (any ... -> (listof any))
list-ref : ((listof X) natural-number -> X)
list? : (any -> boolean)
member : (any (listof any) -> boolean)
memq : (any (listof any) -> (union false list))
memv : (any (listof any) -> (union false list))

```



```

null : empty
null? : (any -> boolean)
pair? : (any -> boolean)
rest : ((cons Y (listof X)) -> (listof X))
reverse : ((listof any) -> list)
second : ((cons Z (cons Y (listof X))) -> Y)
seventh : ((listof Y) -> Y)
sixth : ((listof Y) -> Y)
third : ((cons W (cons Z (cons Y (listof X)))) -> Y)

```

### Posns

```

make-posn : (number number -> posn)
posn-x : (posn -> number)
posn-y : (posn -> number)
posn? : (anything -> boolean)
set-posn-x! : (posn number -> void)
set-posn-y! : (posn number -> void)

```

### Characters

```

char->integer : (char -> integer)
char-alphabetic? : (char -> boolean)
char-ci<=? : (char char char ... -> boolean)
char-ci<? : (char char char ... -> boolean)
char-ci=? : (char char char ... -> boolean)
char-ci>=? : (char char char ... -> boolean)
char-ci>? : (char char char ... -> boolean)
char-downcase : (char -> char)
char-lower-case? : (char -> boolean)
char-numeric? : (char -> boolean)
char-upcase : (char -> char)
char-upper-case? : (char -> boolean)
char-whitespace? : (char -> boolean)
char<=? : (char char char ... -> boolean)
char<? : (char char char ... -> boolean)
char=? : (char char char ... -> boolean)
char>=? : (char char char ... -> boolean)
char>? : (char char char ... -> boolean)
char? : (any -> boolean)

```

### Strings

```

format : (string any ... -> string)
list->string : ((listof char) -> string)
make-string : (nat char -> string)
string : (char ... -> string)
string->list : (string -> (listof char))
string->number : (string -> (union number false))
string->symbol : (string -> symbol)
string-append : (string ... -> string)
string-ci<=? : (string string string ... -> boolean)

```

```

string-ci<? : (string string string ... -> boolean)
string-ci=? : (string string string ... -> boolean)
string-ci>=? : (string string string ... -> boolean)
string-ci>? : (string string string ... -> boolean)
string-copy : (string -> string)
string-length : (string -> nat)
string-ref : (string nat -> char)
string<=? : (string string string ... -> boolean)
string<? : (string string string ... -> boolean)
string=? : (string string string ... -> boolean)
string>=? : (string string string ... -> boolean)
string>? : (string string string ... -> boolean)
string? : (any -> boolean)
substring : (string nat nat -> string)

```

### Images

```

image=? : (image image -> boolean)
image? : (any -> boolean)

```

### Misc

```

=~/ : (real real non-negative-real -> boolean)
eof : eof
eof-object? : (any -> boolean)
eq? : (any any -> boolean)
equal? : (any any -> boolean)
equal~/ : (any any non-negative-real -> boolean)
eqv? : (any any -> boolean)
error : (symbol string -> void)
exit : (-> void)
force : (delay -> any)
identity : (any -> any)
promise? : (any -> boolean)
struct? : (any -> boolean)
void : (-> void)
void? : (any -> boolean)

```

### Higher-Order Functions

```

andmap : ((X -> boolean) (listof X) -> boolean)
apply : ((X-1 ... X-N -> Y)
         X-1
         ...
         X-i
         (list X-i+1 ... X-N)
         ->
         Y)
argmax : ((X -> real) (listof X) -> X)
argmin : ((X -> real) (listof X) -> X)
build-list : (nat (nat -> X) -> (listof X))
build-string : (nat (nat -> char) -> string)

```

```

compose : ((Y-1 -> Z)
           ...
           (Y-N -> Y-N-1)
           (X-1 ... X-N -> Y-N)
           ->
           (X-1 ... X-N -> Z))
filter : ((X -> boolean) (listof X) -> (listof X))
foldl : ((X Y -> Y) Y (listof X) -> Y)
foldr : ((X Y -> Y) Y (listof X) -> Y)
for-each : ((any ... -> any) (listof any) ... -> void)
map : ((X ... -> Z) (listof X) ... -> (listof Z))
memf : ((X -> boolean)
        (listof X)
        ->
        (union false (listof X)))
ormap : ((X -> boolean) (listof X) -> boolean)
procedure? : (any -> boolean)
quicksort : ((listof X) (X X -> boolean) -> (listof X))
sort : ((listof X) (X X -> boolean) -> (listof X))

```

### Reading and Printing

```

display : (any -> void)
newline : (-> void)
pretty-print : (any -> void)
print : (any -> void)
printf : (string any ... -> void)
read : (-> sexp)
write : (any -> void)

```

### Vectors

```

build-vector : (nat (nat -> X) -> (vectorof X))
make-vector : (number X -> (vectorof X))
vector : (X ... -> (vector X ...))
vector-length : ((vector X) -> nat)
vector-ref : ((vector X) nat -> X)
vector-set! : ((vectorof X) nat X -> void)
vector? : (any -> boolean)

```

### Boxes

```

box : (any -> box)
box? : (any -> boolean)
set-box! : (box any -> void)
unbox : (box -> any)

```

## 5.1 define

---

```
(define (id id ...) expr)  
(define id expr)
```

The same as Intermediate with Lambda's `define`, except that a function is allowed to accept zero arguments.

## 5.2 `define-struct`

---

```
(define-struct structid (fieldid ...))
```

The same as Intermediate's `define-struct`, but defines an additional set of operations:

- `set-structid-fieldid!` : takes an instance of the structure and a value, and changes the instance's field to the given value.

## 5.3 `lambda`

---

```
(lambda (id ...) expr)
```

The same as Intermediate with Lambda's `lambda`, except that a function is allowed to accept zero arguments.

## 5.4 **Function Calls**

---

```
(expr expr ...)
```

A function call in Advanced is the same as an Intermediate with Lambda function call, except that zero arguments are allowed.

---

```
(#%app expr expr ...)
```

A function call can be written with  `#%app`, though it's practically never written that way.

## 5.5 begin

---

```
(begin expr expr ...)
```

Evaluates the *exprs* in order from left to right. The value of the `begin` expression is the value of the last *expr*.

## 5.6 begin0

---

```
(begin0 expr expr ...)
```

Evaluates the *exprs* in order from left to right. The value of the `begin` expression is the value of the first *expr*.

## 5.7 set!

---

```
(set! id expr)
```

Evaluates *expr*, and then changes the definition *id* to have *expr*'s value. The *id* must be defined or bound by `letrec`, `let`, or `let*`.

## 5.8 delay

---

```
(delay expr)
```

Produces a “promise” to evaluate *expr*. The *expr* is not evaluated until the promise is forced through the `force` operator; when the promise is forced, the result is recorded, so that any further `force` of the promise always produces the remembered value.

## 5.9 shared

---

```
(shared ([id expr] ...) expr)
```

Like `letrec`, but when an *expr* next to an *id* is a `cons`, `list`, `vector`, quasiquoted ex-

pression, or *make-structid* from a *define-struct*, the *expr* can refer directly to any *id*, not just *ids* defined earlier. Thus, *shared* can be used to create cyclic data structures.

## 5.10 let

---

```
(let ([id expr] ...) expr)
(let id ([id expr] ...) expr)
```

The first form of *let* is the same as Intermediate’s *let*.

The second form is equivalent to a *recur* form.

## 5.11 recur

---

```
(recur id ([id expr] ...) expr)
```

A short-hand recursion construct. The first *id* corresponds to the name of the recursive function. The parenthesized *ids* are the function’s arguments, and each corresponding *expr* is a value supplied for that argument in an initial starting call of the function. The last *expr* is the body of the function.

More precisely, a *recur* form

```
(recur func-id ([arg-id arg-expr] ...)
  body-expr)
```

is equivalent to

```
((local [(define (func-id arg-id ...)
  body-expr)]
  func-id)
  arg-expr ...)
```

## 5.12 case

---

```
(case expr [(choice ...) expr] ... [(choice ...) expr])
```

A *case* form contains one or more “lines” that are surrounded by parentheses or square brackets. Each line contains a sequence of choices—numbers and names for symbols—and

an answer *expr*. The initial *expr* is evaluated, and the resulting value is compared to the choices in each line, where the lines are considered in order. The first line that contains a matching choice provides an answer *expr* whose value is the result of the whole case expression. If none of the lines contains a matching choice, it is an error.

---

```
(case expr [(choice ...) expr] ... [else expr])
```

This form of case is similar to the prior one, except that the final `else` clause is always taken if no prior line contains a choice matching the value of the initial *expr*. In other words, so there is no possibility to “fall off the end” of the case form.

### 5.13 when and unless

---

```
(when expr expr)
```

The first *expr* (known as the “test” expression) is evaluated. If it evaluates to `true`, the result of the when expression is the result of evaluating the second *expr*, otherwise the result is `(void)` and the second *expr* is not evaluated. If the result of evaluating the test *expr* is neither `true` nor `false`, it is an error.

---

```
(unless expr expr)
```

Like when, but the second *expr* is evaluated when the first *expr* produces `false` instead of `true`.

### 5.14 Primitive Operations

---

```
* : (num num num ... -> num)
```

Purpose: to compute the product of all of the input numbers

---

```
+ : (num num num ... -> num)
```

Purpose: to compute the sum of the input numbers

---

```
- : (num num ... -> num)
```

Purpose: to subtract the second (and following) number(s) from the first; negate the number

if there is only one argument

---

`/ : (num num num ... -> num)`

Purpose: to divide the first by the second (and all following) number(s); try `(/ 3 4)` and `(/ 3 2 2)` only the first number can be zero.

---

`< : (real real real ... -> boolean)`

Purpose: to compare real numbers for less-than

---

`<= : (real real real ... -> boolean)`

Purpose: to compare real numbers for less-than or equality

---

`= : (num num num ... -> boolean)`

Purpose: to compare numbers for equality

---

`> : (real real real ... -> boolean)`

Purpose: to compare real numbers for greater-than

---

`>= : (real real ... -> boolean)`

Purpose: to compare real numbers for greater-than or equality

---

`abs : (real -> real)`

Purpose: to compute the absolute value of a real number

---

`acos : (num -> num)`

Purpose: to compute the arccosine (inverse of cos) of a number

---

`add1 : (number -> number)`

Purpose: to compute a number one larger than a given number



---

`angle` : (num -> real)

Purpose: to extract the angle from a complex number

---

`asin` : (num -> num)

Purpose: to compute the arcsine (inverse of sin) of a number

---

`atan` : (num -> num)

Purpose: to compute the arctan (inverse of tan) of a number

---

`ceiling` : (real -> int)

Purpose: to determine the closest integer above a real number

---

`complex?` : (any -> boolean)

Purpose: to determine whether some value is complex

---

`conjugate` : (num -> num)

Purpose: to compute the conjugate of a complex number

---

`cos` : (num -> num)

Purpose: to compute the cosine of a number (radians)

---

`cosh` : (num -> num)

Purpose: to compute the hyperbolic cosine of a number

---

`current-seconds` : (-> int)

Purpose: to compute the current time in seconds elapsed (since a platform-specific starting date)

---

`denominator` : (rat -> int)

Purpose: to compute the denominator of a rational

---

```
e : real
```

Purpose: Euler's number

---

```
even? : (integer -> boolean)
```

Purpose: to determine if some value is even or not

---

```
exact->inexact : (num -> num)
```

Purpose: to convert an exact number to an inexact one

---

```
exact? : (num -> boolean)
```

Purpose: to determine whether some number is exact

---

```
exp : (num -> num)
```

Purpose: to compute e raised to a number

---

```
expt : (num num -> num)
```

Purpose: to compute the power of the first to the second number

---

```
floor : (real -> int)
```

Purpose: to determine the closest integer below a real number

---

```
gcd : (int int ... -> int)
```

Purpose: to compute the greatest common divisor

---

```
imag-part : (num -> real)
```

Purpose: to extract the imaginary part from a complex number

---

`inexact->exact` : (num -> num)

Purpose: to approximate an inexact number by an exact one

---

`inexact?` : (num -> boolean)

Purpose: to determine whether some number is inexact

---

`integer->char` : (int -> char)

Purpose: to lookup the character that corresponds to the given integer in the ASCII table (if any)

---

`integer?` : (any -> boolean)

Purpose: to determine whether some value is an integer (exact or inexact)

---

`lcm` : (int int ... -> int)

Purpose: to compute the least common multiple of two integers

---

`log` : (num -> num)

Purpose: to compute the base-e logarithm of a number

---

`magnitude` : (num -> real)

Purpose: to determine the magnitude of a complex number

---

`make-polar` : (real real -> num)

Purpose: to create a complex from a magnitude and angle

---

`max` : (real real ... -> real)

Purpose: to determine the largest number

---

`min` : (real real ... -> real)

Purpose: to determine the smallest number

---

`modulo` : (int int -> int)

Purpose: to find the remainder of the division of the first number by the second; try (modulo 4 3) (modulo 4 -3)

---

`negative?` : (number -> boolean)

Purpose: to determine if some value is strictly smaller than zero

---

`number->string` : (num -> string)

Purpose: to convert a number to a string

---

`number?` : (any -> boolean)

Purpose: to determine whether some value is a number

---

`numerator` : (rat -> int)

Purpose: to compute the numerator of a rational

---

`odd?` : (integer -> boolean)

Purpose: to determine if some value is odd or not

---

`pi` : real

Purpose: the ratio of a circle's circumference to its diameter

---

`positive?` : (number -> boolean)

Purpose: to determine if some value is strictly larger than zero

---

`quotient` : (int int -> int)

Purpose: to divide the first integer into the second; try (quotient 3 4) and (quotient 4 3)

---

```
random : (int -> int)
```

Purpose: to generate a random natural number less than some given integer

---

```
rational? : (any -> boolean)
```

Purpose: to determine whether some value is a rational number

---

```
real-part : (num -> real)
```

Purpose: to extract the real part from a complex number

---

```
real? : (any -> boolean)
```

Purpose: to determine whether some value is a real number

---

```
remainder : (int int -> int)
```

Purpose: to determine the remainder of dividing the first by the second integer

---

```
round : (real -> int)
```

Purpose: to round a real number to an integer (rounds to even to break ties)

---

```
sgn : (real -> (union 1 1.0 0 0.0 -1 -1.0))
```

Purpose: to compute the sign of a real number

---

```
sin : (num -> num)
```

Purpose: to compute the sine of a number (radians)

---

```
sinh : (num -> num)
```

Purpose: to compute the hyperbolic sine of a number

---

```
sqr : (num -> num)
```

Purpose: to compute the square of a number

---

```
sqrt : (num -> num)
```

Purpose: to compute the square root of a number

---

```
sub1 : (number -> number)
```

Purpose: to compute a number one smaller than a given number

---

```
tan : (num -> num)
```

Purpose: to compute the tangent of a number (radians)

---

```
zero? : (number -> boolean)
```

Purpose: to determine if some value is zero or not

---

```
boolean=? : (boolean boolean -> boolean)
```

Purpose: to determine whether two booleans are equal

---

```
boolean? : (any -> boolean)
```

Purpose: to determine whether some value is a boolean

---

```
false? : (any -> boolean)
```

Purpose: to determine whether a value is false

---

```
not : (boolean -> boolean)
```

Purpose: to compute the negation of a boolean value

---

```
symbol->string : (symbol -> string)
```

Purpose: to convert a symbol to a string

---

`symbol=?` : (symbol symbol -> boolean)

Purpose: to determine whether two symbols are equal

---

`symbol?` : (any -> boolean)

Purpose: to determine whether some value is a symbol

---

`append` : ((listof any) ... -> (listof any))

Purpose: to create a single list from several

---

```
assq : (X
      (listof (cons X Y))
      ->
      (union false (cons X Y)))
```

Purpose: to determine whether some item is the first item of a pair in a list of pairs

---

```
caaar : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        W)
```

Purpose: to select the first item of the first list in the first list of a list

---

```
caadr : ((cons
         (cons (cons W (listof Z)) (listof Y))
         (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
caar : ((cons (cons Z (listof Y)) (listof X)) -> Z)
```

Purpose: to select the first item of the first list in a list

---

```
cadar : ((cons (cons W (cons Z (listof Y))) (listof X))
        ->
        Z)
```

Purpose: to select the second item of the first list of a list

---

```
caddr : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
caddr : ((cons W (cons Z (cons Y (listof X)))) -> Y)
```

Purpose: to select the third item of a non-empty list

---

```
cadr : ((cons Z (cons Y (listof X))) -> Y)
```

Purpose: to select the second item of a non-empty list

---

```
car : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
cdaar : ((cons
          (cons (cons W (listof Z)) (listof Y))
          (listof X))
        ->
        (listof Z))
```

Purpose: to select the rest of the first list in the first list of a list

---

```
cdadr : ((cons W (cons (cons Z (listof Y)) (listof X)))
        ->
        (listof Y))
```

Purpose: to select the rest of the first list in the rest of a list

---

```
cdar : ((cons (cons Z (listof Y)) (listof X))
        ->
        (listof Y))
```



Purpose: to select the rest of a non-empty list in a list

---

```
cddar : ((cons (cons W (cons Z (listof Y))) (listof X))  
        ->  
        (listof Y))
```

Purpose: to select the rest of the rest of the first list of a list

---

```
cdddr : ((cons W (cons Z (cons Y (listof X))))  
        ->  
        (listof X))
```

Purpose: to select the rest of the rest of the rest of a list

---

```
cddr : ((cons Z (cons Y (listof X))) -> (listof X))
```

Purpose: to select the rest of the rest of a list

---

```
cdr : ((cons Y (listof X)) -> (listof X))
```

Purpose: to select the rest of a non-empty list

---

```
cons : (X (listof X) -> (listof X))
```

Purpose: to construct a list

---

```
cons? : (any -> boolean)
```

Purpose: to determine whether some value is a constructed list

---

```
eighth : ((listof Y) -> Y)
```

Purpose: to select the eighth item of a non-empty list

---

```
empty? : (any -> boolean)
```

Purpose: to determine whether some value is the empty list

---

```
fifth : ((listof Y) -> Y)
```

Purpose: to select the fifth item of a non-empty list

---

```
first : ((cons Y (listof X)) -> Y)
```

Purpose: to select the first item of a non-empty list

---

```
fourth : ((listof Y) -> Y)
```

Purpose: to select the fourth item of a non-empty list

---

```
length : ((listof any) -> number)
```

Purpose: to compute the number of items on a list

---

```
list : (any ... -> (listof any))
```

Purpose: to construct a list of its arguments

---

```
list-ref : ((listof X) natural-number -> X)
```

Purpose: to extract the indexed item from the list

---

```
list? : (any -> boolean)
```

Purpose: to determine whether some value is a list

---

```
member : (any (listof any) -> boolean)
```

Purpose: to determine whether some value is on the list (comparing values with equal?)

---

```
memq : (any (listof any) -> (union false list))
```

Purpose: to determine whether some value is on some list (comparing values with eq?)

---

```
memv : (any (listof any) -> (union false list))
```

Purpose: to determine whether some value is on the list (comparing values with eqv?)

---

`null` : empty

Purpose: the empty list

---

`null?` : (any -> boolean)

Purpose: to determine whether some value is the empty list

---

`pair?` : (any -> boolean)

Purpose: to determine whether some value is a constructed list

---

`rest` : ((cons Y (listof X)) -> (listof X))

Purpose: to select the rest of a non-empty list

---

`reverse` : ((listof any) -> list)

Purpose: to create a reversed version of a list

---

`second` : ((cons Z (cons Y (listof X))) -> Y)

Purpose: to select the second item of a non-empty list

---

`seventh` : ((listof Y) -> Y)

Purpose: to select the seventh item of a non-empty list

---

`sixth` : ((listof Y) -> Y)

Purpose: to select the sixth item of a non-empty list

---

`third` : ((cons W (cons Z (cons Y (listof X)))) -> Y)

Purpose: to select the third item of a non-empty list

---

`make-posn` : (number number -> posn)

Purpose: to construct a posn

---

`posn-x` : (posn -> number)

Purpose: to extract the x component of a posn

---

`posn-y` : (posn -> number)

Purpose: to extract the y component of a posn

---

`posn?` : (anything -> boolean)

Purpose: to determine if its input is a posn

---

`set-posn-x!` : (posn number -> void)

Purpose: to update the x component of a posn

---

`set-posn-y!` : (posn number -> void)

Purpose: to update the y component of a posn

---

`char->integer` : (char -> integer)

Purpose: to lookup the number that corresponds to the given character in the ASCII table (if any)

---

`char-alphabetic?` : (char -> boolean)

Purpose: to determine whether a character represents an alphabetic character

---

`char-ci<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it) in a case-insensitive manner

---

`char-ci<?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another in a case-insensitive manner

---

`char-ci=?` : (char char char ... -> boolean)

Purpose: to determine whether two characters are equal in a case-insensitive manner

---

`char-ci>=?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another (or is equal to it) in a case-insensitive manner

---

`char-ci>?` : (char char char ... -> boolean)

Purpose: to determine whether a character succeeds another in a case-insensitive manner

---

`char-downcase` : (char -> char)

Purpose: to determine the equivalent lower-case character

---

`char-lower-case?` : (char -> boolean)

Purpose: to determine whether a character is a lower-case character

---

`char-numeric?` : (char -> boolean)

Purpose: to determine whether a character represents a digit

---

`char-upcase` : (char -> char)

Purpose: to determine the equivalent upper-case character

---

`char-upper-case?` : (char -> boolean)

Purpose: to determine whether a character is an upper-case character

---

`char-whitespace?` : (char -> boolean)

Purpose: to determine whether a character represents space

---

`char<=?` : (char char char ... -> boolean)

Purpose: to determine whether a character precedes another (or is equal to it)

---

`char<? : (char char char ... -> boolean)`

Purpose: to determine whether a character precedes another

---

`char=? : (char char char ... -> boolean)`

Purpose: to determine whether two characters are equal

---

`char>=? : (char char char ... -> boolean)`

Purpose: to determine whether a character succeeds another (or is equal to it)

---

`char>? : (char char char ... -> boolean)`

Purpose: to determine whether a character succeeds another

---

`char? : (any -> boolean)`

Purpose: to determine whether a value is a character

---

`format : (string any ... -> string)`

Purpose: to format a string, possibly embedding values

---

`list->string : ((listof char) -> string)`

Purpose: to convert a s list of characters into a string

---

`make-string : (nat char -> string)`

Purpose: to produce a string of given length from a single given character

---

`string : (char ... -> string)`

Purpose: (string c1 c2 ...) builds a string

---

`string->list` : (string -> (listof char))

Purpose: to convert a string into a list of characters

---

`string->number` : (string -> (union number false))

Purpose: to convert a string into a number, produce false if impossible

---

`string->symbol` : (string -> symbol)

Purpose: to convert a string into a symbol

---

`string-append` : (string ... -> string)

Purpose: to juxtapose the characters of several strings

---

`string-ci<=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another (or is equal to it) in a case-insensitive manner

---

`string-ci<?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another in a case-insensitive manner

---

`string-ci=?` : (string string string ... -> boolean)

Purpose: to compare two strings character-wise in a case-insensitive manner

---

`string-ci>=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it) in a case-insensitive manner

---

`string-ci>?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another in a case-insensitive manner

---

`string-copy` : (string -> string)

Purpose: to copy a string

---

`string-length` : (string -> nat)

Purpose: to determine the length of a string

---

`string-ref` : (string nat -> char)

Purpose: to extract the i-th character from a string

---

`string<=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another (or is equal to it)

---

`string<?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically precedes another

---

`string=?` : (string string string ... -> boolean)

Purpose: to compare two strings character-wise

---

`string>=?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another (or is equal to it)

---

`string>?` : (string string string ... -> boolean)

Purpose: to determine whether one string alphabetically succeeds another

---

`string?` : (any -> boolean)

Purpose: to determine whether a value is a string

---

`substring` : (string nat nat -> string)



Purpose: to extract the substring starting at a 0-based index up to the second 0-based index (exclusive)

---

```
image=? : (image image -> boolean)
```

Purpose: to determine whether two images are equal

---

```
image? : (any -> boolean)
```

Purpose: to determine whether a value is an image

---

```
=~ : (real real non-negative-real -> boolean)
```

Purpose: to check whether two real numbers are within some amount (the third argument) of either other

---

```
eof : eof
```

Purpose: the end-of-file value

---

```
eof-object? : (any -> boolean)
```

Purpose: to determine whether some value is the end-of-file value

---

```
eq? : (any any -> boolean)
```

Purpose: to compare two values

---

```
equal? : (any any -> boolean)
```

Purpose: to determine whether two values are structurally equal

---

```
equal~? : (any any non-negative-real -> boolean)
```

Purpose: to compare like equal? on the first two arguments, except using =~ in the case of real numbers

---

```
eqv? : (any any -> boolean)
```

Purpose: to compare two values

---

```
error : (symbol string -> void)
```

Purpose: to signal an error

---

```
exit : (-> void)
```

Purpose: to exit the running program

---

```
force : (delay -> any)
```

Purpose: to find the delayed value; see also delay

---

```
identity : (any -> any)
```

Purpose: to return the argument unchanged

---

```
promise? : (any -> boolean)
```

Purpose: to determine if a value is delayed

---

```
struct? : (any -> boolean)
```

Purpose: to determine whether some value is a structure

---

```
void : (-> void)
```

Purpose: produces a void value

---

```
void? : (any -> boolean)
```

Purpose: to determine if a value is void

---

```
andmap : ((X -> boolean) (listof X) -> boolean)
```

Purpose: (andmap p (list x-1 ... x-n)) = (and (p x-1) (and ... (p x-n)))

---

```
apply : ((X-1 ... X-N -> Y)
         X-1
         ...
         X-i
         (list X-i+1 ... X-N)
         ->
         Y)
```

Purpose: to apply a function using items from a list as the arguments

---

```
argmax : ((X -> real) (listof X) -> X)
```

Purpose: to find the (first) element of the list that minimizes the output of the function

---

```
argmin : ((X -> real) (listof X) -> X)
```

Purpose: to find the (first) element of the list that minimizes the output of the function

---

```
build-list : (nat (nat -> X) -> (listof X))
```

Purpose: (build-list n f) = (list (f 0) ... (f (- n 1)))

---

```
build-string : (nat (nat -> char) -> string)
```

Purpose: (build-string n f) = (string (f 0) ... (f (- n 1)))

---

```
compose : ((Y-1 -> Z)
           ...
           (Y-N -> Y-N-1)
           (X-1 ... X-N -> Y-N)
           ->
           (X-1 ... X-N -> Z))
```

Purpose: to compose a sequence of procedures into a single procedure

---

```
filter : ((X -> boolean) (listof X) -> (listof X))
```

Purpose: to construct a list from all those items on a list for which the predicate holds

---

```
foldl : ((X Y -> Y) Y (listof X) -> Y)
```

Purpose: (foldl f base (list x-1 ... x-n)) = (f x-n ... (f x-1 base))

---

`foldr` : ((X Y -> Y) Y (listof X) -> Y)

Purpose: (foldr f base (list x-1 ... x-n)) = (f x-1 ... (f x-n base))

---

`for-each` : ((any ... -> any) (listof any) ... -> void)

Purpose: to apply a function to each item on one or more lists for effect only

---

`map` : ((X ... -> Z) (listof X) ... -> (listof Z))

Purpose: to construct a new list by applying a function to each item on one or more existing lists

---

`memf` : ((X -> boolean)  
          (listof X)  
          ->  
          (union false (listof X)))

Purpose: to determine whether the first argument produces true for some value in the second argument

---

`ormap` : ((X -> boolean) (listof X) -> boolean)

Purpose: (ormap p (list x-1 ... x-n)) = (or (p x-1) (or ... (p x-n)))

---

`procedure?` : (any -> boolean)

Purpose: to determine if a value is a procedure

---

`quicksort` : ((listof X) (X X -> boolean) -> (listof X))

Purpose: to construct a list from all items on a list in an order according to a predicate

---

`sort` : ((listof X) (X X -> boolean) -> (listof X))

Purpose: to construct a list from all items on a list in an order according to a predicate

---

`display` : (any -> void)

Purpose: to print the argument to stdout (without quotes on symbols and strings, etc.)

---

`newline` : (-> void)

Purpose: to print a newline to stdout

---

`pretty-print` : (any -> void)

Purpose: like write, but with standard newlines and indentation

---

`print` : (any -> void)

Purpose: to print the argument as a value to stdout

---

`printf` : (string any ... -> void)

Purpose: to format the rest of the arguments according to the first argument and print it to stdout

---

`read` : (-> sexp)

Purpose: to read input from the user

---

`write` : (any -> void)

Purpose: to print the argument to stdout (in a traditional style that is somewhere between print and display)

---

`build-vector` : (nat (nat -> X) -> (vectorof X))

Purpose: to construct a vector

---

`make-vector` : (number X -> (vectorof X))

Purpose: to construct a vector

---

`vector` : (X ... -> (vector X ...))

Purpose: to construct a vector

---

```
vector-length : ((vector X) -> nat)
```

Purpose: to determine the length of a vector

---

```
vector-ref : ((vector X) nat -> X)
```

Purpose: to extract an element from a vector

---

```
vector-set! : ((vectorof X) nat X -> void)
```

Purpose: to update a vector

---

```
vector? : (any -> boolean)
```

Purpose: to determine if a value is a vector

---

```
box : (any -> box)
```

Purpose: to construct a box

---

```
box? : (any -> boolean)
```

Purpose: to determine if a value is a box

---

```
set-box! : (box any -> void)
```

Purpose: to update a box

---

```
unbox : (box -> any)
```

Purpose: to extract the boxed value

## 5.15 Unchanged Forms

---

```
(local [definition ...] expr)
```

```
(letrec ([id expr-for-let] ...) expr)  
(let* ([id expr-for-let] ...) expr)
```

The same as Intermediate's local, letrec, and let\*.

---

```
(cond [expr expr] ... [expr expr])  
else
```

The same as Beginning's cond, except that else can be used with case.

---

```
(if expr expr expr)
```

The same as Beginning's if.

---

```
(and expr expr expr ...)  
(or expr expr expr ...)
```

The same as Beginning's and and or.

---

```
(time expr)
```

The same as Intermediate's time.

---

```
(check-expect expr expr)  
(check-within expr expr expr)  
(check-error expr expr)
```

The same as Beginning's check-expect, etc.

---

```
empty : empty?  
true : boolean?  
false : boolean?
```

Constants for the empty list, true, and false.

---

```
(require string)
```

The same as Beginning's require.

## Index

##%app, 12  
##%app, 71  
##%app, 132  
##%app, 101  
\*, 72  
\*, 101  
\*, 42  
\*, 135  
\*, 16  
+, 42  
+, 72  
+, 135  
+, 16  
+, 102  
-, 135  
-, 16  
-, 72  
-, 102  
-, 42  
/, 72  
/, 102  
/, 42  
/, 16  
/, 136  
<, 42  
<, 72  
<, 136  
<, 16  
<, 102  
<=, 42  
<=, 73  
<=, 16  
<=, 102  
<=, 136  
=, 16  
=, 136  
=, 43  
=, 73  
=, 102  
=~ , 59  
=~ , 119  
=~ , 33  
=~ , 153  
=~ , 89  
>, 102  
>, 73  
>, 136  
>, 43  
>, 16  
>=, 17  
>=, 73  
>=, 136  
>=, 102  
>=, 43  
abs, 17  
abs, 136  
abs, 102  
abs, 43  
abs, 73  
acos, 73  
acos, 17  
acos, 43  
acos, 103  
acos, 136  
add1, 136  
add1, 73  
add1, 103  
add1, 17  
add1, 43  
Advanced Student, 124  
and, 13  
and, 123  
and, 61  
and, 93  
and, 159  
and, 13  
andmap, 154  
andmap, 90  
andmap, 120  
angle, 103  
angle, 43  
angle, 137



angle, 73  
 angle, 17  
 append, 143  
 append, 49  
 append, 79  
 append, 109  
 append, 23  
 apply, 120  
 apply, 155  
 apply, 91  
 argmax, 91  
 argmax, 155  
 argmax, 120  
 argmin, 121  
 argmin, 155  
 argmin, 91  
 asin, 137  
 asin, 103  
 asin, 17  
 asin, 73  
 asin, 43  
 assq, 50  
 assq, 23  
 assq, 80  
 assq, 109  
 assq, 143  
 atan, 137  
 atan, 43  
 atan, 73  
 atan, 17  
 atan, 103  
 begin, 133  
 begin, 133  
 begin0, 133  
 begin0, 133  
 Beginning Student, 5  
 Beginning Student with List Abbreviations,  
 35  
 boolean=?, 49  
 boolean=?, 22  
 boolean=?, 108  
 boolean=?, 142  
 boolean=?, 79  
 boolean?, 142  
 boolean?, 79  
 boolean?, 108  
 boolean?, 49  
 boolean?, 23  
 box, 158  
 box?, 158  
 build-list, 155  
 build-list, 91  
 build-list, 121  
 build-string, 155  
 build-string, 121  
 build-string, 91  
 build-vector, 157  
 caaar, 24  
 caaar, 50  
 caaar, 109  
 caaar, 143  
 caaar, 80  
 caadr, 110  
 caadr, 50  
 caadr, 80  
 caadr, 143  
 caadr, 24  
 caar, 110  
 caar, 80  
 caar, 24  
 caar, 50  
 caar, 143  
 cadar, 144  
 cadar, 24  
 cadar, 110  
 cadar, 80  
 cadar, 50  
 caddr, 50  
 caddr, 80  
 caddr, 144  
 caddr, 24  
 caddr, 110  
 caddr, 24  
 caddr, 80

caddr, 144  
caddr, 110  
caddr, 50  
cadr, 110  
cadr, 81  
cadr, 24  
cadr, 144  
cadr, 51  
car, 24  
car, 110  
car, 51  
car, 144  
car, 81  
case, 134  
case, 134  
cdaar, 81  
cdaar, 110  
cdaar, 51  
cdaar, 144  
cdaar, 25  
cdadr, 144  
cdadr, 51  
cdadr, 111  
cdadr, 25  
cdadr, 81  
cdar, 25  
cdar, 144  
cdar, 111  
cdar, 81  
cdar, 51  
cddar, 111  
cddar, 81  
cddar, 51  
cddar, 145  
cddar, 25  
cdddr, 145  
cdddr, 25  
cdddr, 81  
cdddr, 51  
cdddr, 111  
cddr, 145  
cddr, 52  
cddr, 82  
cddr, 25  
cddr, 111  
cdr, 82  
cdr, 111  
cdr, 145  
cdr, 52  
cdr, 25  
ceiling, 137  
ceiling, 17  
ceiling, 103  
ceiling, 43  
ceiling, 74  
char->integer, 55  
char->integer, 148  
char->integer, 114  
char->integer, 28  
char->integer, 85  
char-alphabetic?, 55  
char-alphabetic?, 85  
char-alphabetic?, 148  
char-alphabetic?, 28  
char-alphabetic?, 114  
char-ci<=?, 85  
char-ci<=?, 55  
char-ci<=?, 148  
char-ci<=?, 114  
char-ci<=?, 29  
char-ci<?, 55  
char-ci<?, 85  
char-ci<?, 148  
char-ci<?, 115  
char-ci<?, 29  
char-ci=?, 55  
char-ci=?, 85  
char-ci=?, 149  
char-ci=?, 29  
char-ci=?, 115  
char-ci>=?, 149  
char-ci>=?, 85  
char-ci>=?, 29  
char-ci>=?, 115

char-ci>=?, 55  
char-ci>?, 29  
char-ci>?, 85  
char-ci>?, 55  
char-ci>?, 149  
char-ci>?, 115  
char-downcase, 149  
char-downcase, 29  
char-downcase, 115  
char-downcase, 85  
char-downcase, 55  
char-lower-case?, 149  
char-lower-case?, 115  
char-lower-case?, 85  
char-lower-case?, 55  
char-lower-case?, 29  
char-numeric?, 29  
char-numeric?, 56  
char-numeric?, 86  
char-numeric?, 149  
char-numeric?, 115  
char-upcase, 149  
char-upcase, 56  
char-upcase, 86  
char-upcase, 115  
char-upcase, 29  
char-upper-case?, 115  
char-upper-case?, 86  
char-upper-case?, 30  
char-upper-case?, 56  
char-upper-case?, 149  
char-whitespace?, 115  
char-whitespace?, 56  
char-whitespace?, 86  
char-whitespace?, 30  
char-whitespace?, 149  
char<=?, 30  
char<=?, 116  
char<=?, 149  
char<=?, 56  
char<=?, 86  
char<=?, 56  
char<?, 116  
char<?, 150  
char<?, 86  
char<?, 30  
char=?, 86  
char=?, 30  
char=?, 150  
char=?, 56  
char=?, 116  
char>=?, 86  
char>=?, 56  
char>=?, 116  
char>=?, 150  
char>=?, 30  
char>?, 56  
char>?, 30  
char>?, 150  
char>?, 86  
char>?, 116  
char?, 57  
char?, 150  
char?, 87  
char?, 30  
char?, 116  
check-error, 61  
check-error, 159  
check-error, 14  
check-error, 93  
check-error, 123  
check-expect, 61  
check-expect, 93  
check-expect, 14  
check-expect, 123  
check-expect, 159  
check-within, 93  
check-within, 14  
check-within, 159  
check-within, 123  
check-within, 61  
complex?, 137  
complex?, 17  
complex?, 103

[complex?](#), 44  
[complex?](#), 74  
[compose](#), 91  
[compose](#), 155  
[compose](#), 121  
[cond](#), 12  
[cond](#), 12  
[cond](#), 159  
[cond](#), 93  
[cond](#), 61  
[cond](#), 123  
[conjugate](#), 44  
[conjugate](#), 74  
[conjugate](#), 137  
[conjugate](#), 103  
[conjugate](#), 18  
[cons](#), 111  
[cons](#), 52  
[cons](#), 145  
[cons](#), 82  
[cons](#), 26  
[cons?](#), 145  
[cons?](#), 26  
[cons?](#), 82  
[cons?](#), 111  
[cons?](#), 52  
[cos](#), 18  
[cos](#), 103  
[cos](#), 137  
[cos](#), 74  
[cos](#), 44  
[cosh](#), 103  
[cosh](#), 18  
[cosh](#), 74  
[cosh](#), 137  
[cosh](#), 44  
[current-seconds](#), 44  
[current-seconds](#), 18  
[current-seconds](#), 104  
[current-seconds](#), 74  
[current-seconds](#), 137  
[define](#), 131  
[define](#), 10  
[define](#), 70  
[define](#), 101  
[define](#), 61  
[define](#), 132  
[define](#), 10  
[define](#), 101  
[define](#), 70  
[define-struct](#), 132  
[define-struct](#), 11  
[define-struct](#), 70  
[define-struct](#), 122  
[define-struct](#), 11  
[define-struct](#), 70  
[define-struct](#), 61  
[define-struct](#), 132  
[delay](#), 133  
[delay](#), 133  
[denominator](#), 18  
[denominator](#), 137  
[denominator](#), 74  
[denominator](#), 44  
[denominator](#), 104  
[display](#), 157  
[e](#), 138  
[e](#), 18  
[e](#), 104  
[e](#), 44  
[e](#), 74  
[eighth](#), 112  
[eighth](#), 82  
[eighth](#), 145  
[eighth](#), 26  
[eighth](#), 52  
[else](#), 159  
[else](#), 93  
[else](#), 123  
[else](#), 13  
[else](#), 61  
[empty](#), 14  
[empty](#), 61  
[empty](#), 123

empty, 93  
empty, 14  
empty, 159  
empty?, 145  
empty?, 52  
empty?, 26  
empty?, 82  
empty?, 112  
eof, 33  
eof, 119  
eof, 59  
eof, 153  
eof, 89  
eof-object?, 119  
eof-object?, 60  
eof-object?, 153  
eof-object?, 90  
eof-object?, 33  
eq?, 153  
eq?, 33  
eq?, 60  
eq?, 119  
eq?, 90  
equal?, 153  
equal?, 33  
equal?, 60  
equal?, 119  
equal?, 90  
equal~?, 34  
equal~?, 119  
equal~?, 153  
equal~?, 60  
equal~?, 90  
eqv?, 120  
eqv?, 60  
eqv?, 153  
eqv?, 90  
eqv?, 34  
error, 34  
error, 60  
error, 120  
error, 154  
error, 90  
even?, 104  
even?, 44  
even?, 138  
even?, 18  
even?, 74  
exact->inexact, 44  
exact->inexact, 74  
exact->inexact, 18  
exact->inexact, 138  
exact->inexact, 104  
exact?, 104  
exact?, 75  
exact?, 138  
exact?, 18  
exact?, 45  
exit, 60  
exit, 154  
exit, 34  
exit, 90  
exit, 120  
exp, 104  
exp, 75  
exp, 45  
exp, 138  
exp, 18  
expt, 19  
expt, 75  
expt, 45  
expt, 104  
expt, 138  
false, 123  
false, 61  
false, 93  
false, 159  
false, 15  
false?, 79  
false?, 23  
false?, 108  
false?, 49  
false?, 142  
fifth, 112

[fifth](#), 26  
[fifth](#), 145  
[fifth](#), 52  
[fifth](#), 82  
[filter](#), 121  
[filter](#), 91  
[filter](#), 155  
[first](#), 52  
[first](#), 26  
[first](#), 146  
[first](#), 82  
[first](#), 112  
[floor](#), 45  
[floor](#), 138  
[floor](#), 19  
[floor](#), 104  
[floor](#), 75  
[foldl](#), 92  
[foldl](#), 121  
[foldl](#), 155  
[foldr](#), 121  
[foldr](#), 156  
[foldr](#), 92  
[for-each](#), 156  
[for-each](#), 121  
[for-each](#), 92  
[force](#), 154  
[format](#), 30  
[format](#), 116  
[format](#), 87  
[format](#), 150  
[format](#), 57  
[fourth](#), 26  
[fourth](#), 146  
[fourth](#), 82  
[fourth](#), 112  
[fourth](#), 52  
Function Calls, 132  
Function Calls, 12  
Function Calls, 71  
Function Calls, 101  
[gcd](#), 45  
[gcd](#), 104  
[gcd](#), 138  
[gcd](#), 19  
[gcd](#), 75  
*How to Design Programs Languages*, 1  
Identifiers, 14  
Identifiers, 72  
[identity](#), 90  
[identity](#), 60  
[identity](#), 120  
[identity](#), 154  
[identity](#), 34  
[if](#), 13  
[if](#), 159  
[if](#), 93  
[if](#), 13  
[if](#), 123  
[if](#), 61  
[imag-part](#), 105  
[imag-part](#), 138  
[imag-part](#), 45  
[imag-part](#), 75  
[imag-part](#), 19  
[image=?](#), 33  
[image=?](#), 89  
[image=?](#), 59  
[image=?](#), 153  
[image=?](#), 119  
[image?](#), 33  
[image?](#), 119  
[image?](#), 59  
[image?](#), 153  
[image?](#), 89  
[inexact->exact](#), 19  
[inexact->exact](#), 75  
[inexact->exact](#), 105  
[inexact->exact](#), 45  
[inexact->exact](#), 139  
[inexact?](#), 75  
[inexact?](#), 105  
[inexact?](#), 139  
[inexact?](#), 19

[inexact?](#), 45  
[integer->char](#), 105  
[integer->char](#), 139  
[integer->char](#), 19  
[integer->char](#), 75  
[integer->char](#), 45  
[integer?](#), 19  
[integer?](#), 45  
[integer?](#), 139  
[integer?](#), 76  
[integer?](#), 105  
Intermediate Student, 63  
Intermediate Student with Lambda, 94  
[lambda](#), 132  
[lambda](#), 101  
[lambda](#), 70  
[lambda](#), 61  
[lambda](#), 132  
[lambda](#), 11  
[lambda](#), 101  
[lcm](#), 105  
[lcm](#), 76  
[lcm](#), 139  
[lcm](#), 19  
[lcm](#), 46  
[length](#), 112  
[length](#), 53  
[length](#), 83  
[length](#), 26  
[length](#), 146  
[let](#), 134  
[let](#), 122  
[let](#), 71  
[let](#), 134  
[let\\*](#), 71  
[let\\*](#), 122  
[let\\*](#), 159  
[letrec](#), 122  
[letrec](#), 71  
[letrec](#), 159  
[letrec](#), [let](#), and [let\\*](#), 71  
[list](#), 146  
[list](#), 112  
[list](#), 83  
[list](#), 26  
[list](#), 53  
[list\\*](#), 53  
[list\\*](#), 112  
[list\\*](#), 83  
[list\\*](#), 27  
[list->string](#), 30  
[list->string](#), 116  
[list->string](#), 87  
[list->string](#), 150  
[list->string](#), 57  
[list-ref](#), 146  
[list-ref](#), 83  
[list-ref](#), 27  
[list-ref](#), 53  
[list-ref](#), 112  
[list?](#), 146  
[local](#), 70  
[local](#), 158  
[local](#), 122  
[local](#), 70  
[log](#), 76  
[log](#), 46  
[log](#), 139  
[log](#), 20  
[log](#), 105  
[magnitude](#), 139  
[magnitude](#), 20  
[magnitude](#), 105  
[magnitude](#), 46  
[magnitude](#), 76  
[make-polar](#), 20  
[make-polar](#), 46  
[make-polar](#), 76  
[make-polar](#), 105  
[make-polar](#), 139  
[make-posn](#), 28  
[make-posn](#), 84  
[make-posn](#), 147  
[make-posn](#), 114

make-posn, 54  
make-string, 87  
make-string, 31  
make-string, 57  
make-string, 116  
make-string, 150  
make-vector, 157  
map, 156  
map, 121  
map, 92  
max, 106  
max, 76  
max, 139  
max, 20  
max, 46  
member, 113  
member, 146  
member, 53  
member, 27  
member, 83  
memf, 156  
memf, 92  
memf, 122  
memq, 53  
memq, 146  
memq, 113  
memq, 83  
memq, 27  
memv, 27  
memv, 113  
memv, 53  
memv, 83  
memv, 146  
min, 139  
min, 46  
min, 20  
min, 76  
min, 106  
modulo, 106  
modulo, 76  
modulo, 140  
modulo, 46  
modulo, 20  
negative?, 76  
negative?, 106  
negative?, 140  
negative?, 46  
negative?, 20  
newline, 157  
not, 108  
not, 142  
not, 23  
not, 79  
not, 49  
null, 113  
null, 83  
null, 27  
null, 53  
null, 147  
null?, 147  
null?, 53  
null?, 113  
null?, 27  
null?, 83  
number->string, 140  
number->string, 20  
number->string, 46  
number->string, 106  
number->string, 76  
number?, 20  
number?, 106  
number?, 140  
number?, 47  
number?, 77  
numerator, 47  
numerator, 106  
numerator, 140  
numerator, 20  
numerator, 77  
odd?, 21  
odd?, 77  
odd?, 47  
odd?, 106  
odd?, 140



or, 13  
 or, 13  
 or, 159  
 or, 93  
 or, 61  
 or, 123  
 ormap, 156  
 ormap, 92  
 ormap, 122  
 pair?, 147  
 pair?, 113  
 pair?, 83  
 pair?, 27  
 pair?, 53  
 pi, 47  
 pi, 106  
 pi, 140  
 pi, 77  
 pi, 21  
 positive?, 77  
 positive?, 21  
 positive?, 140  
 positive?, 47  
 positive?, 106  
 posn-x, 54  
 posn-x, 114  
 posn-x, 148  
 posn-x, 28  
 posn-x, 84  
 posn-y, 54  
 posn-y, 84  
 posn-y, 28  
 posn-y, 114  
 posn-y, 148  
 posn?, 28  
 posn?, 114  
 posn?, 84  
 posn?, 148  
 posn?, 54  
 pretty-print, 157  
 Primitive Calls, 12  
 Primitive Operation Names, 101  
 Primitive Operations, 135  
 Primitive Operations, 42  
 Primitive Operations, 16  
 Primitive Operations, 72  
 print, 157  
 printf, 157  
 procedure?, 156  
 procedure?, 92  
 procedure?, 122  
 promise?, 154  
 Quasiquote, 41  
 quasiquote, 41  
 quicksort, 122  
 quicksort, 92  
 quicksort, 156  
 Quote, 41  
 quote, 14  
 quote, 41  
 quotient, 107  
 quotient, 21  
 quotient, 47  
 quotient, 77  
 quotient, 140  
 random, 77  
 random, 47  
 random, 141  
 random, 107  
 random, 21  
 rational?, 107  
 rational?, 21  
 rational?, 141  
 rational?, 47  
 rational?, 77  
 read, 157  
 real-part, 107  
 real-part, 21  
 real-part, 77  
 real-part, 47  
 real-part, 141  
 real?, 107  
 real?, 141  
 real?, 78

real?, 47  
real?, 21  
recur, 134  
recur, 134  
remainder, 48  
remainder, 141  
remainder, 21  
remainder, 78  
remainder, 107  
require, 15  
require, 62  
require, 15  
require, 159  
require, 93  
require, 123  
rest, 113  
rest, 54  
rest, 27  
rest, 84  
rest, 147  
reverse, 54  
reverse, 27  
reverse, 113  
reverse, 147  
reverse, 84  
round, 78  
round, 48  
round, 22  
round, 107  
round, 141  
second, 147  
second, 84  
second, 113  
second, 54  
second, 28  
set!, 133  
set!, 133  
set-box!, 158  
set-posn-x!, 148  
set-posn-y!, 148  
seventh, 113  
seventh, 54  
seventh, 28  
seventh, 147  
seventh, 84  
sgn, 48  
sgn, 141  
sgn, 107  
sgn, 78  
sgn, 22  
shared, 133  
shared, 133  
sin, 141  
sin, 22  
sin, 48  
sin, 107  
sin, 78  
sinh, 22  
sinh, 78  
sinh, 108  
sinh, 48  
sinh, 141  
sixth, 147  
sixth, 84  
sixth, 114  
sixth, 28  
sixth, 54  
sort, 156  
sort, 122  
sort, 92  
sqr, 78  
sqr, 141  
sqr, 108  
sqr, 48  
sqr, 22  
sqrt, 22  
sqrt, 108  
sqrt, 48  
sqrt, 142  
sqrt, 78  
string, 150  
string, 57  
string, 87  
string, 31

string, 117  
string->list, 117  
string->list, 31  
string->list, 57  
string->list, 151  
string->list, 87  
string->number, 57  
string->number, 117  
string->number, 87  
string->number, 31  
string->number, 151  
string->symbol, 87  
string->symbol, 151  
string->symbol, 57  
string->symbol, 117  
string->symbol, 31  
string-append, 117  
string-append, 57  
string-append, 31  
string-append, 151  
string-append, 87  
string-ci<=?, 117  
string-ci<=?, 87  
string-ci<=?, 31  
string-ci<=?, 57  
string-ci<=?, 151  
string-ci<?, 58  
string-ci<?, 88  
string-ci<?, 117  
string-ci<?, 151  
string-ci<?, 31  
string-ci=?, 117  
string-ci=?, 58  
string-ci=?, 31  
string-ci=?, 88  
string-ci=?, 151  
string-ci>=?, 117  
string-ci>=?, 32  
string-ci>=?, 58  
string-ci>=?, 151  
string-ci>=?, 88  
string-ci>?, 88  
string-ci>?, 32  
string-ci>?, 58  
string-ci>?, 118  
string-ci>?, 151  
string-copy, 58  
string-copy, 32  
string-copy, 118  
string-copy, 88  
string-copy, 152  
string-length, 58  
string-length, 32  
string-length, 88  
string-length, 152  
string-length, 118  
string-ref, 118  
string-ref, 58  
string-ref, 32  
string-ref, 88  
string-ref, 152  
string<=?, 32  
string<=?, 152  
string<=?, 58  
string<=?, 118  
string<=?, 88  
string<?, 152  
string<?, 88  
string<?, 58  
string<?, 32  
string<?, 118  
string=?, 152  
string=?, 32  
string=?, 118  
string=?, 89  
string=?, 59  
string>=?, 32  
string>=?, 89  
string>=?, 152  
string>=?, 118  
string>=?, 59  
string>?, 152  
string>?, 118  
string>?, 33

`string>?`, 89  
`string>?`, 59  
`string?`, 118  
`string?`, 59  
`string?`, 152  
`string?`, 33  
`string?`, 89  
`struct?`, 90  
`struct?`, 34  
`struct?`, 120  
`struct?`, 154  
`struct?`, 60  
`sub1`, 142  
`sub1`, 78  
`sub1`, 22  
`sub1`, 108  
`sub1`, 48  
`substring`, 119  
`substring`, 89  
`substring`, 59  
`substring`, 152  
`substring`, 33  
`symbol->string`, 109  
`symbol->string`, 23  
`symbol->string`, 79  
`symbol->string`, 142  
`symbol->string`, 49  
`symbol=?`, 143  
`symbol=?`, 79  
`symbol=?`, 23  
`symbol=?`, 49  
`symbol=?`, 109  
`symbol?`, 109  
`symbol?`, 23  
`symbol?`, 49  
`symbol?`, 79  
`symbol?`, 143  
Symbols, 14  
`tan`, 78  
`tan`, 142  
`tan`, 22  
`tan`, 48  
`tan`, 108  
Test Cases, 14  
`third`, 28  
`third`, 84  
`third`, 54  
`third`, 147  
`third`, 114  
`time`, 71  
`time`, 159  
`time`, 123  
`time`, 71  
`true`, 15  
`true`, 93  
`true`, 61  
`true`, 123  
`true`, 159  
`true` and `false`, 15  
`unbox`, 158  
Unchanged Forms, 61  
Unchanged Forms, 158  
Unchanged Forms, 122  
Unchanged Forms, 93  
`unless`, 135  
`unquote`, 41  
`unquote-splicing`, 42  
`vector`, 157  
`vector-length`, 158  
`vector-ref`, 158  
`vector-set!`, 158  
`vector?`, 158  
`void`, 154  
`void?`, 154  
`when`, 135  
`when` and `unless`, 135  
`write`, 157  
`zero?`, 108  
`zero?`, 49  
`zero?`, 22  
`zero?`, 142  
`zero?`, 79