## Lisp & Scheme

Lisp (*Lis*t *P*rocessing Language) is one of the oldest programming languages still in wide use.

It was developed in the late 50s and early 60s by John McCarthy.

Its innovations include:

- Support of symbolic computations.
- A *functional programming style* without emphasis on assignments and side-effects.
- A naturally recursive programming style.
- Dynamic (run-time) type checking.



- Dynamic data structures (lists, binary trees) that grow without limit.
- Automatic garbage collection to manage memory.
- Functions are treated as “first class” values; they may be passed as arguments, returned as result values, stored in data structures, and created during execution.
- A formal semantics (written in Lisp) that defines the meaning of all valid programs.
- An Integrated Programming Environment to create, edit and test Lisp programs.



## Scheme

Scheme is a recent dialect of Lisp.

It uses lexical (static) scoping.

It supports true first-class functions.

It provides program-level access to control flow via *continuation* functions.



## Atomic (Primitive) Data Types

Symbols:

Essentially the same form as identifiers. Similar to enumeration values in C and C++.

Very flexible in structure; essentially any sequence of printable characters is allowed; anything that starts a valid number (except + or -) *may not* start a symbol.

Valid symbols include:

```
abc  hello-world   +  <=!
```

Integers:

Any sequence of digits, optionally prefixed with a + or -. Usually unlimited in length.

Reals:

A floating point number in a decimal format (**123.456**) or in exponential format (**1.23e45**). A leading sign and a signed exponent are allowed (**-12.3**, **10.0e-20**).

Rationals:

Rational numbers of the form integer/integer (e.g., **1/3** or **9/7**) with an optional leading sign (**-1/2**, **+7/8**).

Complex:

Complex numbers of the form num+num i or num-num i, where num is an integer or real number. Example include **1+3i**, **-1.5-2.5i**, **0+1i**).



String:

A sequence of characters delimited by double quotes. Double quotes and backslashes must be escaped using a backslash. For example

**"Hello World" "\"Wow!\""**

Character:

A single character prefixed by **#**. For example, **#\a**, **#\0**, **#**, **#\#**. Two special characters are **#\space** and **#\newline**.

Boolean:

True is represented as **#t** and false is represented as **#f**.



## Binary Trees

Binary trees are also called *S-Expressions* in Lisp and Scheme.

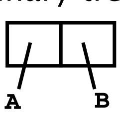
They are of the form

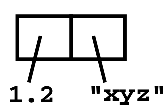
( item . item )

where item is any atomic value or any S-Expression. For example:

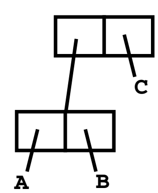
```
( A . B )
(1.2  .  "xyz" )
( (A . B ) . C )
( A . (B . C ) )
```

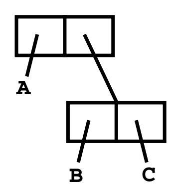
S-Expressions are linearizations of binary trees:






S-Expressions are built and accessed using the predefined functions *cons*, *car* and *cdr*.

cons builds a new S-Expression from two S-Expressions that represent the left and right children.

cons(E1,E2) = (E1 . E2)

car returns are left subtree of an S-Expression.

car (E1 . E2) = E1

cdr returns are right subtree of an S-Expression.

cdr (E1 . E2) = E2

# Lists

In Lisp and Scheme lists are a special, widely-used form of S-Expressions.

**()** represents the empty or null list

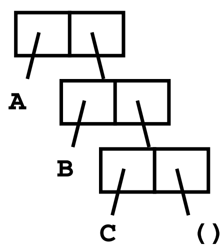
**(A)** is the list containing **A**.
By definition, **(A)** ≡ **(A . () )**

**(A B)** represents the list containing **A** and **B**. By definition,
**(A B)** ≡ **(A . (B . () ) )**

In general, **(A B C ... Z)** ≡

**(A . (B . (C . ... (Z . () ) ... )))**

**(A B C )**≡






# Function Calls

In List and Scheme, function calls are represented as lists.

**(A B C)** means:

Evaluate **A** (to a function)

Evaluate **B** and **C** (as parameters)

Call **A** with **B** and **C** as its parameters

Use the value returned by the call as the "meaning" of **(A B C)**.

**cons**, **car** and **cdr** are predefined symbols bound to built-in functions that build and access lists and S-Expressions.

Literals (of type integer, real, rational, complex, string, character and boolean) evaluate to themselves.



For example (⇒ means "evaluates to")

**(cons 1 2)** ⇒ **(1 . 2)**

**(cons 1 () )** ⇒ **(1)**

**(car (cons 1 2))** ⇒ **1**

**(cdr (cons 1 ()))** ⇒ **()**

But,

**(car (1 2))** fails during execution!

Why?

The expression **(1 2)** looks like a call, but **1** isn't a function! We need some way to "quote" symbols and lists we *don't* want evaluated.

**(quote arg)**

is a special function that returns its argument *unevaluated*.



Thus **(quote (1 2))** doesn't try to evaluate the list **(1 2)**; it just returns it.

Since quotation is so often used, it may be abbreviated using a single quote. That is

**(quote arg)** ≡ **'arg**

Thus

**(car '(a b c))** ⇒ **a**

**(cdr '( (A) (B) (C)))** ⇒
**( (B) (C) )**

**(cons 'a '1)** ⇒ **(a . 1)**

But,

**('cdr '(A B))** fails!

Why?

## User-defined Functions

The list

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

evaluates to a function with **(args)** as its argument list and **(body)** as the function body.

No quotes are needed for **(args)** or **(body)**.

Thus

**(lambda (x) (+ x 1))** evaluates to the increment function.

Similarly,

**((lambda (x) (+ x 1)) 10)** ⇒ **11**



We can bind values and functions to global symbols using the **define** function.

The general form is

```
(define id object)
```

**id** is not evaluated but **object** is. **id** is bound to the value object evaluates to.

For example,

```
(define pi  3.1415926535)
(define plus1
   (lambda (x) (+ x 1)) )
(define pi*2  (* pi 2))
```

Once a symbol is defined, it evaluates to the value it is bound to:

**(plus1 12)** ⇒ **13**



Since functions are frequently defined, we may abbreviate

```
(define id
  (lambda (args) (body)) )
```

as

```
(define (id args) (body) )
```

Thus

```
(define (plus1 x) (+ x 1))
```



## Conditional Expressions in Scheme

A *predicate* is a function that returns a boolean value. By convention, in Scheme, predicate names end with "?"

For example,

```
number?  symbol?  equal?
null?    list?
```

In conditionals, **#f** is false, and everything else, including **#t**, is true.

The **if** expression is

```
(if pred E1 E2)
```

First **pred** is evaluated. Depending on its value (**#f** or not), either **E1** or **E2** is evaluated (but not both) and returned as the value of the **if** expression.

For example,

```
(if  (=  1  (+  0 1))
     'Yes
     'No
)
```

```
(define
  (fact n)
  (if  (= n  0)
       1
       (*  n  (fact  (- n 1)))
  )
)
```



## Generalized Conditional

This is similar to a switch or case:

```
(cond
    (p1  e1)
    (p2  e2)
     ...
    (else  en)
)
```

Each of the predicates (**p1**, **p2**, ...) is evaluated until one is true (≠ **#f**). Then the corresponding expression (**e1**, **e2**, ...) is evaluated and returned as the value of the **cond**. **else** acts like a predicate that is always true.

Example:

```
(cond
   ((= a 1)  2)
   ((= a 2)  3)
   (else     4)
)
```