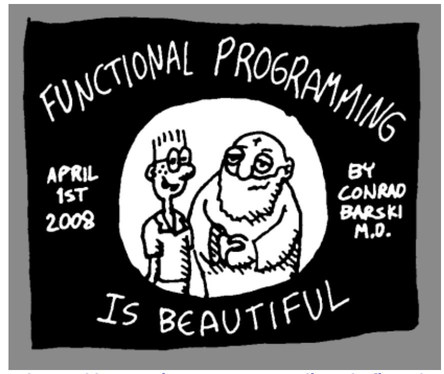
Functional Programming in Scheme and Lisp



http://www.lisperati.com/landoflisp/

Overview

- In a functional programming language, functions are first class objects
- You can create them, put them in data structures, compose them, specialize them, apply them to arguments, etc.
- We'll look at how functional programming things are done in Lisp

eval

- Remember: Lisp code is just an s-expression
- You can call Lisp's evaluation process with the eval function

```
> (define s (list 'cadr ' ' (one two three)))
> s
(cadr ' (one two three))
> (eval s)
two
> (eval (list 'cdr (car '((quote (a . b)) c))))
b
```

apply

- *apply* takes a function & a list of arguments for it & returns the result of applying the function to them

```
> (apply + '(1 2 3))
6
```

- It can be given any number of arguments, so long as the last is a list:

```
> (apply + 1 2 '(3 4 5))
15
```

- A simple version of apply could be written as

```
(define (apply f list) (eval (cons f list)))
```

lambda

- The *define* special form creates a function and gives it a name
- However, functions don't have to have names, and we don't need to use *define* to create them
- The primitive way to create functions is to use the *lambda* special form
- These are often called lambda expressions, e.g.
  (lambda (x) (+ x 1))

lambda expression

- A *lambda expression* is a list of the symbol *lambda*, followed by a list of *parameters*, followed by a *body* of one or more expressions:

```
> (define f (lambda (x) (+ x 2)))
> f
#<proceedure:f>
> (f 100)
102
> ( (lambda (x) (+ x 2)) 100)
102
```

Lambda expression

- lambda is a special form
- When evaluated, it creates a function and returns a reference to it
- The function does not have a name
- A lambda expression can be the first element of a function call:

```
> ( (lambda  (x)  (+  x  100))  1)
101
```

- Other languages like python and javascript have adopted the idea

define vs. define

```
(define (add2 x)
    (+ x 2) )

(define add2
   (lambda (x) (+ x 2)))

(define add2 #f)
(set! add2
    (lambda (x) (+ x 2)))
```

- The define special form comes in two varieties
- The three expressions to the right are entirely equivalent
- The first define form is just more familiar and convenient when defining a function

Functions as objects

- While many PLs allow functions as arguments, nameless lambda functions add flexibility

```
> (sort '((a 100)(b 10)(c 50))
        (lambda (x y) (< (second x) (second y))))
((b 10) (c 50) (a 100))
```

- There is no need to give the function a name

lambdas in other languages

- Lambda expressions are found in many modern languages, e.g., Python:

```
>>> f = lambda x,y: x*x + y
>>> f
<function <lambda> at 0x10048a230>
>>> f(2, 3)
7
>>> (lambda x,y: x*x+y)(2,3)
7
```

Mapping functions

- Lisp & Scheme have several mapping functions
- ***map*** *(mapcar in Lisp)* is the most useful
- It takes a function and ≥1 lists and returns a list of the results of applying the function to elements taken from each list

```
> (map abs '(3 -4 2 -5 -6))
(3 4 2 5 6)
> (map + ‘(1 2 3) (4 5 6))
(5 7 9)
> (map + ‘(1 2 3) ‘(4 5 6) ‘(7 8 9))
(12 15 18)
```

More map examples

```
> (map cons '(a b c) '(1 2 3))
((a . 1) (b . 2) (c . 3))
> (map (lambda  (x)  (+  x  10))  '(1  2  3))
(11  12  13)
> (map + '(1 2 3) '(4 5))
```

map: all lists must have same size; arguments were:
#<procedure:+> (1 2 3) (4 5)
=== context ===
/Applications/PLT/collects/scheme/private/misc.ss:74:7

Defining map

Defining a simple "one argument" version of map is easy

```
(define (map1 func list)
   (if (null? list)
       null
       (cons (func (first list))
             (map1 func (rest list)))))
```

Define Lisp's every and some

- *every* and *some* take a predicate and one or more sequences
- When given just one sequence, they test whether the elements satisfy the predicate

```
> (every  odd?  '(1  3  5))
#t
> (some  even?  '(1  2  3))
#t
```

- If given >1 sequences, the predicate takes as many args as there are sequences and args are drawn one at a time from them:

```
> (every  >  '(1  3  5)  '(0  2  4))
#t
```

Defining every is easy

```
(define (every1 f list)
   ;; note the use of the and function
   (if (null? list)
       #t
       (and (f (first list))
            (every1 f (rest list)))))
```

Define some similarly

```
(define (some1 f list)
   (if (null? list)
       #f
       (or (f (first list))
           (some1 f (rest list)))))
```

Will this work?

- You can prove that P is true for some list element by showing that it isn't false for every one
- Will this work?

```
> (define (some1 f list)
     (not (every1 (lambda (x) (not (f x)))  list)))
> (some1 odd? '(2 4 6 7 8))
#t
> (some1 (lambda (x) (> x 10)) '(4 8 10 12))
#t
```

filter

(filter <f> <list>) returns a list of the elements of <list> which satisfy the predicate <f>

```
> (filter odd? '(0 1 2 3 4 5))
(1 3 5)
> (filter (lambda (x) (> x 98.6))
    '(101.1 98.6 98.1 99.4 102.2))
(101.1 99.4 102.2)
```

Example: filter

```
(define (filter1 func list)
  ;; returns a list of elements of list where funct is true
  (cond ((null? list) null)
        ((func (first list))
         (cons (first list) (filter1 func (rest list))))
        (#t (filter1 func (rest list)))))

> (filter1 even? '(1 2 3 4 5 6 7))
(2 4 6)
```

Example: filter

- Define *integers* as a function that returns a list of integers between a min and max

```
(define (integers min max)
  (if (> min max)
      null
      (cons min (integers (add1 min) max))))
```

- Do prime? as a predicate that is true of prime numbers and false otherwise

```
> (filter prime? (integers 2 20) )
(2 3 5 7 11 13 17 19)
```

Here's another pattern

- We often want to do something like sum the elements of a sequence

```
(define (sum-list l)
  (if (null? l)
      0
      (+ (first l) (sum-list (rest l)))))
```

- Other times we want their product

```
(define (multiply-list l)
  (if (null? l)
      1
      (* (first l) (multiply-list (rest l)))))
```

Here's another pattern

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```
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```

- Other times we want their product

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(define (multiply-list l)
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```

Example: reduce

- Reduce takes (i) a function, (ii) a final value and (iii) a list of arguments

  Reduce of +, 0, (v1 v2 v3 … vn) is just

  V1 + V2 + V3 + … Vn + 0
- In Scheme/Lisp notation:

```
> (reduce + 0 '(1 2 3 4 5))
15
(reduce * 1 '(1 2 3 4 5))
120
```

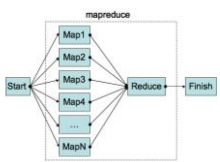
Example: reduce

```
(define (reduce function final list)
  (if (null? list)
      final
      (function
         (first list)
         (reduce function final (rest list)))))
```

Using reduce

```
(define (sum-list list)
   ;; returns the sum of the list elements
   (reduce + 0 list))
(define (mul-list list)
   ;; returns the sum of the list elements
   (reduce * 1 list))
(define (copy-list list)
   ;; copies the top level of a list
   (reduce cons '() list))
(define (append-list list)
   ;; appends all of the sublists in a list
   (reduce append '() list))
```

The roots of mapReduce



- MapReduce is a software framework developed by Google for parallel computation on large datasets on computer clusters
- It's become an important way to exploit parallel computing using conventional programming languages and techniques.
- See Apache's Hadoop for an open source version
- The framework was inspired by functional programming's map, reduce & side-effect free programs

Function composition

- Math notation: *g•h* is a composition of functions *g* and *h*
- If *f=g•h* then *f(x)=g(h(x)*
- Composing functions is easy in Scheme

```
> compose
#<procedure:compose>
> (define (sq x) (* x x))
> (define (dub x) (* x 2))
> (sq (dub 10))
400
> (dub (sq 10))
200
```

```
> (define sd (compose sq dub))
> (sd 10)
400
> ((compose dub sq) 10)
200
```

Defining compose

- Here's compose for two functions in Scheme
  (define (compose2 f g) (lambda (x) (f (g x))))
- Note that compose calls lambda which returns a new function that applies *f* to the result of applying *g* to *x*
- We'll look at how the variable environments work to support this in the next topic, closures
- But first, let's see how to define a general version of compose taking any number of args

Functions with any number of args

- Defining functions that takes any number of arguments is easy in Scheme

  (define (foo . args) (printf "My args: ~a\n" args)))
- If the parameter list ends in a symbol as opposed to null (cf. dotted pair), then it's value is the list of the remaining arguments' values

  (define (f x y . more-args) …)

  (define (map f . lists) …)

Compose in Scheme

```
(define (compose . FS)
  ;; Returns the identity function if no args given
  (if (null? FS)
      (lambda (x) x)
      (lambda (x) ((first FS) ((apply compose (rest FS)) x)))))
; examples
(define (add-a-bang str) (string-append str "!"))
(define givebang
        (compose string->symbol add-a-bang symbol->string))
(givebang 'set) ; ===> set!
; anonymous composition
((compose sqrt negate square) 5) ; ===> 0+5i
```

A general every

- We can easily re-define other functions to take more than one argument

```
(define (every fn . args)
  (cond ((null? args) #f)
        ((null? (first args)) #t)
        ((apply fn (map first args))
         (apply every fn (map rest args)))
        (else #f)))
```

- (every > '(1 2 3) '(0 2 3)) => #t
- (every > '(1 2 3) '(0 20 3)) => #f

Functional Programming Summary

- Lisp is the archetypal functional programming language
- It treated functions as first-class objects and uses the same representation for data & code
- The FP paradigm is a good match for many problems, esp. ones involving reasoning about or optimizing code or parallel execution
- While no pure FP languages are considered mainstream, many PLs support a FP style