

Scheme

4190.310
Programming Languages
Spring 2014

Lecture 04

Reading assignments: Chapter 10

Scheme

- Scheme is a particularly elegant Lisp
- Interpreter runs a read-eval-print loop
- Things typed into the interpreter are evaluated (recursively) once
- Anything in parentheses is a function call (unless quoted)
- Parentheses are NOT just grouping, as they are in Algol-family languages
- Adding a level of parentheses changes meaning
 - $(+ 3 4) \Rightarrow 7$
 - $((+ 3 4))) \Rightarrow \text{error}$
 - The ' \Rightarrow ' arrow means 'evaluates to'

S-expression

- Symbolic expression
- Used in Lisp
 - A notation for nested list
- Defined inductively
 - An atom
 - An expression of the form $(x . y)$ where x and y are s-expressions
- $(x\ y\ z)$
- $(x . (y . (z . ())))$
- The first element of an S-expression is commonly a function and the remaining elements are arguments to the function
 - Prefix notation or Cambridge polish notation

An Overview of Scheme

- $(+ \ 3 \ 4) \Rightarrow 7$
- $7 \Rightarrow 7$
 - The number 7 is already fully evaluated
- (load “my_Scheme_program”)
 - Input from a file
- $((+ \ 3 \ 4))$
 - a run-time error

Quote

- $(\text{quote } (+\ 3\ 4)) \Rightarrow (+\ 3\ 4)$
- $'(+\ 3\ 4) \Rightarrow (+\ 3\ 4)$
- Every expression has a type in Scheme
 - Generally not determined until run time
 - Predefined functions check dynamically to make sure that their arguments are appropriate types
- $(\text{if } (>\ a\ 0)\ (+\ 2\ 3)\ (+\ 2\ \text{"foo"}))$
 - 5 if a is positive
 - Otherwise a run-time type clash error

Predefined Type Predicates

- (boolean? x)
- (char? x)
- (string? x)
- (symbol? x)
- (number? x)
- (pair? x)
- (list? x)

Symbol in Scheme

- Comparable to what other languages call an identifier
 - Identifiers are permitted to contain a wide variety of punctuation marks
 - (symbol? 'x\$_%:&=*!) \Rightarrow #t
- Boolean value
 - #t
 - #f

Functions

- $(\text{lambda } (x) (* x x)) \Rightarrow \text{function}$
 - A lambda expression does not give its function a name
- When a function is called, the language implementation restores the referencing environment that was in effect when the lambda expression was evaluated
 - Then, it augments this environment with bindings for the formal parameters and evaluates the expression of the function body in order
- $((\text{lambda } (x) (* x x)) 3) \Rightarrow 9$

Functions (contd.)

- Standard functions
 - arithmetic
 - boolean operators
 - equivalence
 - list operators
 - symbol?
 - number?
 - complex?
 - real?
 - rational?
 - integer?
 - ...

Bindings

- Names can be bound to values by introducing a nested scope
- ‘let’ takes two arguments
 - The scope of the bindings produced by let is its second argument only
 - “All at once” semantics

```
(let ((a 3)
      (b 4)
      (square (lambda (x) (* x x)))
      (plus +))
  (sqrt (plus (square a) (square b)))) ⇒ 5.0
```

```
(let ((a 3)
      (let ((a 4)
            (b a))
        (+ a b)))) ⇒ 7
```

Recursion

- let and letrec allow the user to create nested scopes

```
(letrec (fact
        (lambda (n)
          (if (= n 1) 1
              (* n (fact (- n 1))))))
  (fact 5))  $\Rightarrow$  120
```

Conditional Expressions

- $(\text{if } (< 2\ 3)\ 4\ 5) \Rightarrow 4$
- $(\text{if } \#f\ 2\ 3) \Rightarrow 3$
- $(\text{cond } ((< 3\ 2)\ 1) ((< 4\ 3)\ 2) (\text{else } 3)) \Rightarrow 3$
- ‘if’ checks to see whether the first argument evaluates to #t
 - If so, it returns the value of the second argument without evaluating the third
 - Otherwise, it returns the value of the third without evaluating the second
- Conditional expressions treat anything other than #f as true
- Scheme expressions are evaluated in applicative order in general

Creating a Global Binding of a Name

```
(define hypot  
  (lambda (a b)  
    (sqrt (+ (* a a) (* b b)))))  
(hypot 3 4)  $\Rightarrow$  5
```

Lists and Numbers

- `car` - returns the head of a list
 - $(\text{car } '(2\ 3\ 4)) \Rightarrow 2$
 - $'(2\ 3\ 4)$ - a proper list (the final element is the empty list)
 - $(\text{car } '(2)) \Rightarrow ()$
- `cdr` - returns the rest of the list everything after the head
 - $(\text{cdr } '(2\ 3\ 4)) \Rightarrow (3\ 4)$
- `cons` - joins a head to the rest of the list
 - $(\text{cons } 2\ '(3\ 4)) \Rightarrow (2\ 3\ 4)$
 - $(\text{cons } 2\ 3) \Rightarrow (2\ .\ 3)$ (improper list)

Equality Testing and Searching

- `eq?` - tests whether its arguments refer to the same object
 - `(memq 'z '(x y z w)) \Rightarrow (z w)`
 - `(let ((p (lambda (x) x))) (eq? p (lambda (x) x))) \Rightarrow #f`
 - `(let ((p (lambda (x) x))) (eq? p p)) \Rightarrow #t`
 - `(eq? (lambda (x) x) (lambda (x) x)) \Rightarrow #f`
- `eqv?` - tests whether its arguments are provably semantically equivalent
 - `(memv 'z '(x y (z) w)) \Rightarrow #f`
 - `(let ((p (lambda (x) x))) (eqv? p (lambda (x) x))) \Rightarrow #f`
 - `(eqv? (lambda (x) x) (lambda (x) x)) \Rightarrow #f`
- `equal?` - tests whether its arguments have the same recursive structure
 - `(member 'z '(x y (z) w)) \Rightarrow ((z) w)`
 - `(let ((p (lambda (x) x))) (equal? p (lambda (x) x))) \Rightarrow #f`
 - `(equal? (lambda (x) x) (lambda (x) x)) \Rightarrow #f`

Assignments and Sequencing

```
(let ((x 2))  
  (set! x 3)  
  x)  $\Rightarrow$  3
```

```
(let ((l '(a b)))  
  (set-car! l '(c d))  
  (set-cdr! l '(e))  
  l)  $\Rightarrow$  ((c d) e)
```

```
(begin  
  (display "hi")  
  (display "SNU"))
```


Iteration

```
(define iter-fib (lambda (n)
  (do ((i 0 (+ i 1))
      (a 0 b)
      (b 1 (+ a b)))
    ((= i n) b)
    (display b)
    (display " "))))
```

```
(for-each (lambda (a b) (display (* a b)) (newline))
  '(2 4 6) '(3 5 7))
```

Programs as Lists

- Homoiconic
 - Programs look like ordinary data structures, and can be created, modified, and executed on the fly
- eval function
 - Evaluates a list that has been created as a data structure
 - list returns a list consisting of its (evaluated) arguments

```
(define compose
  (lambda (f g)
    (lambda (x) (f (g x)))))
((compose car cdr) '(1 2 3)) ⇒ 2
```

```
(define compose2
  (lambda (f g)
    (eval (list 'lambda '(x) (list f (list g 'x)))
          (scheme-report-environment 5))))
((compose2 car cdr) '(1 2 3)) ⇒ 2
```

Evaluation Order

- Applicative order
 - What you're used to in imperative languages
 - Usually faster
- Normal order
 - Like call-by-name: don't evaluate arg until you need it
 - Sometimes faster
 - Terminates if anything will (Church-Rosser theorem)

```
(define double (lambda (x) (+ x x)))
```

Evaluation Order (contd.)

```
(double (* 3 4))  
⇒ (double 12)  
⇒ (+ 12 12)  
⇒ 24
```

```
(double (* 3 4))  
⇒ (+ (* 3 4) (* 3 4))  
⇒ (+ 12 (* 3 4))  
⇒ (+ 12 12)  
⇒ 24
```

Evaluation Order (contd.)

```
(define switch (lambda (x a b c)
  (cond ((< x 0) a)
        ((= x 0) b)
        (> x 0) c)))
```

```
(switch -1 (+ 1 2) (+ 2 3) (+ 3 4))
⇒ (switch -1 3 (+ 2 3) (+ 3 4))
⇒ (switch -1 3 5 (+ 3 4))
⇒ (switch -1 3 5 7)
⇒ (cond ((< -1 0) 3)
        ((= -1 0) 5)
        (> -1 0) 7))
⇒ (cond (#t 3)
        ((= -1 0) 5)
        (> -1 0) 7))
⇒ 3
```

Evaluation Order (contd.)

```
(define switch (lambda (x a b c)
  (cond ((< x 0) a)
        ((= x 0) b)
        (> x 0) c)))
```

```
(switch -1 (+ 1 2) (+ 2 3) (+ 3 4))
⇒ (cond ((< -1 0) (+ 1 2))
        ((= -1 0) (+ 2 3))
        (> -1 0) (+ 3 4)))
⇒ (cond (#t (+ 1 2))
        ((= -1 0) (+ 2 3))
        (> -1 0) (+ 3 4)))
⇒ (+ 1 2)
⇒ 3
```

Strictness

- Under applicative order evaluation, an unneeded subexpression may not terminate
- A strict language requires all arguments to be well-defined, so applicative order can be used
 - ML, Scheme
- A non-strict language does not require all arguments to be well-defined
 - It requires normal-order evaluation
 - Miranda, Heskell

Lazy Evaluation

- Lazy evaluation gives the best of both worlds
 - But not good in the presence of side effects
- Delay and force in Scheme

```
(define naturals
  (letrec ((next
            (lambda (n) (cons n (delay (next (+ n 1))))))
    (next 1)))
(define head car)
(define tail (lambda (stream) (force (cdr stream)))))
```

```
(head naturals)  $\Rightarrow$  1
(head (tail naturals))  $\Rightarrow$  2
(head (tail (tail naturals)))  $\Rightarrow$  3
```


Lazy Evaluation (contd.)

- Any attempt to evaluate the argument sets the value in the memo as a side effect
- `(double (* 3 4))` will be compiled as `(double (f))`

```
(define double (lambda (x) (+ x x)))
```

```
(define f
  (lambda ()
    (let ((done #f)
          (memo ' ()))
      (code (lambda () (* 3 4))))
    (if done memo
        (begin
          (set! memo (code))
          (set! done #t)
          memo))))))
```

...

```
(double (f)) ⇒ (+ (f) (f))
⇒ (+ 12 (f)) ⇒ (+ 12 12) ⇒ 24
```

Streams

- Source of side effects
 - read will generally return a different value every time it is called
 - multiple calls to display must occur in the proper order if the program is to be considered correct
- One way to avoid these side effects is to model input and output as streams
 - Unbounded-length lists whose elements are generated lazily

```
(define output (my_prog input))  
  
(define driver (lambda (s)  
  (if (null? s) '()  
      (display (car s))  
      (driver (cdr s)))))  
(driver output)
```

Streams (contd.)

- If Scheme employed lazy evaluation of input and output streams, prompts, inputs, and outputs would be interleaved naturally in time

```
(define squares (lambda (s)
  (cons "please enter a number\n"
    (let ((n (car s)))
      (if (eof-object? n) '()
          (cons (* n n)
                (cons #\newline (squares (cdr s))))))))))

(define output (squares input))

(car output)
(cadr output)
(caddr output)
...
```

Higher-Order Functions

- Take a function as argument, or return a function as a result
- Great for building things

```
(map * ' (2 4 6) ' (3 5 7))  $\Rightarrow$  (6 20 42)
```

```
(define fold (lambda (f i l)  
  (if (null? l) i  
      (f (car l) (fold f i (cdr l))))))
```

```
(fold + 0 ' (1 2 3 4 5))
```

```
(fold * 1 ' (1 2 3 4 5))
```

Currying

- After Haskell Curry, the same guy Haskell is named after
- Replacing a multi-argument function with a function that take a single argument and returns a function that expects the remaining arguments
- ML, Miranda, and Haskell have especially nice syntax for curried functions

```
(define curried-plus  
  (lambda (a) (lambda (b) (+ a b))))
```

```
((curried-plus 3) 4)
```

```
(define plus-3 (curried-plus 3))
```

```
(plus-3 4)
```

Currying (contd.)

```
(define curry  
  (lambda (f)  
    (lambda (a)  
      (lambda (b) (+ a b))))))
```

```
((curry +) 3) 4)
```

```
(define curried-plus (curry +))
```