CSE 341
Lecture 20

Mutation; memoization

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Mutation and mutability

Mutating variables

`(set! name expression)`

- Unlike ML, in Scheme all top-level bindings are mutable!

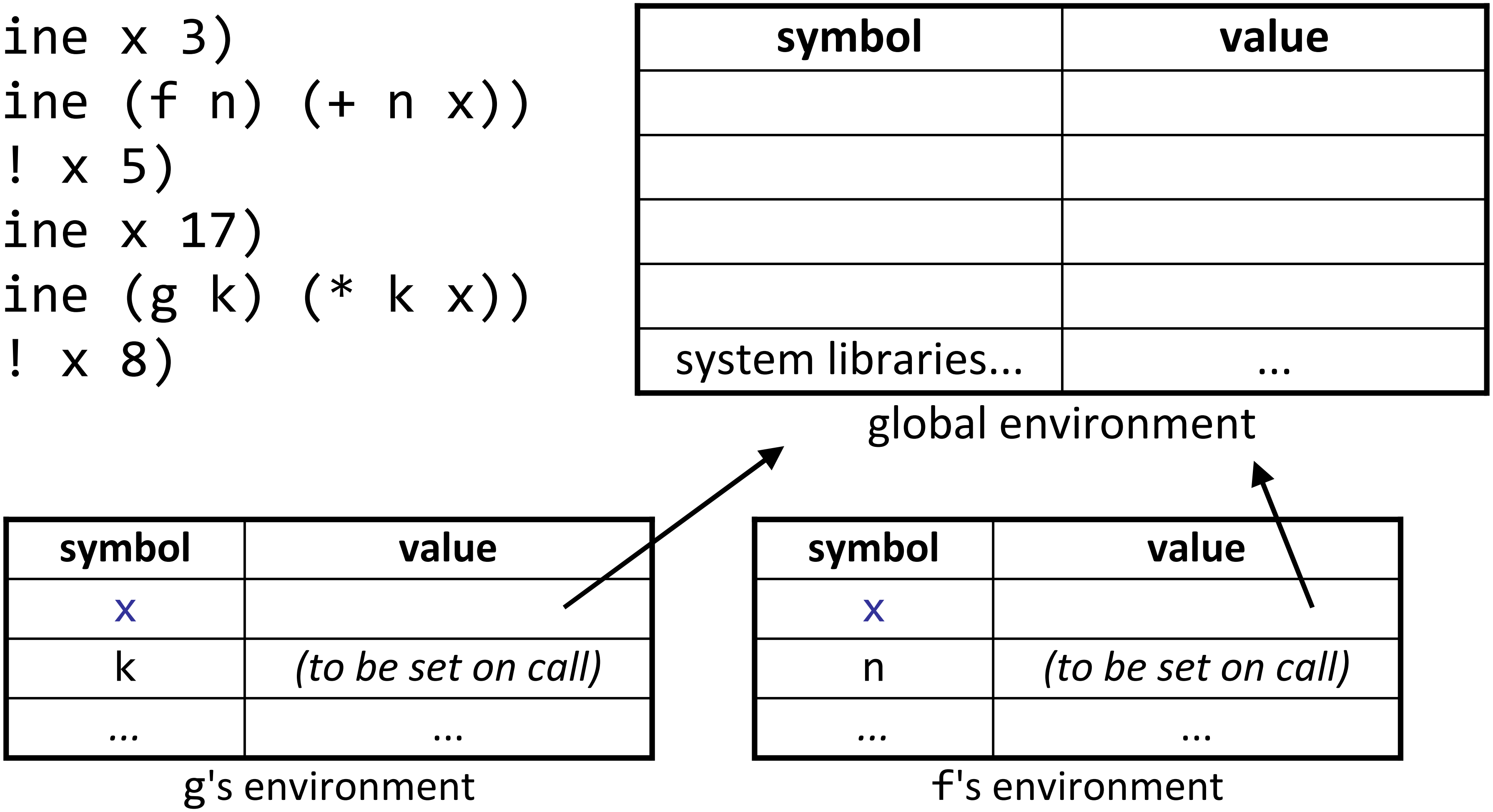
```
> (define x 3)                 ; int x = 3;
> (set! x 5)                    ; x = 5;
```

  - Legal, but changing bound values is generally discouraged.
  - Convention: Any procedure that mutates ends with `!`

Mutations and environment

- What does the following code do to the environment?

```
(define x 3)
(define (f n) (+ n x))
(set! x 5)
(define x 17)
(define (g k) (* k x))
(set! x 8)
```



symbol	value
system libraries...	...

global environment

symbol	value
x	
k	*(to be set on call)*
...	...

g's environment

symbol	value
x	
n	*(to be set on call)*
...	...

f's environment

define vs. set!

- What is the difference between these two procedures?

```
(define x 3)
```

```
(define (f k)
    (define x 5)
    (* x k))
```

```
(define (g k)
    (set! x 5)
    (* x k))
```

- both return the same thing for any given call, but...
  - f defines a local x and uses it; global x is unchanged
  - g mutates the global x and uses its new value

Mutation for "private" variables

- Use let to create a private mutable variable:

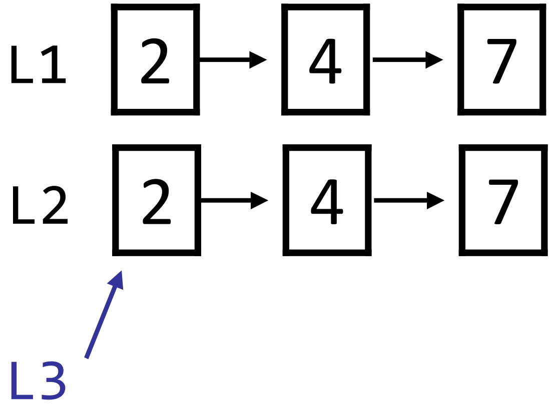
```
(define incr null)     ; stub for procedure
(define get null)      ; stub for procedure
(let ((n 0))
     (set! incr (lambda (i)  ; replace stubs
           (set! n (+ n i))))     ; n += i
     (set! get (lambda () n)))    ; return n
```

```
> (get)
0
> (incr 3)
> (get)
3
```

```
> (incr 8)
> (get)
11
> n
* reference to undefined ...
```

Lists and equality

```
(define L1 '(2 4 7))
(define L2 '(2 4 7))
(define L3 L2)
```

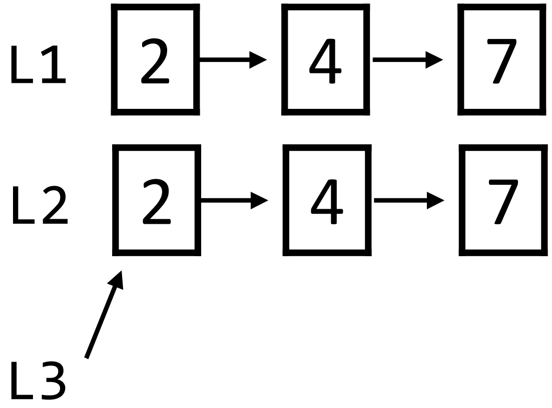


- Scheme lists are linked structures, as in ML
  - two lists declared with the same value are separate lists
  - one list declared to be another list will be a reference to that same list object in memory (shared)

(We didn't care much about this distinction in ML... why?)

Recall: Testing for equality

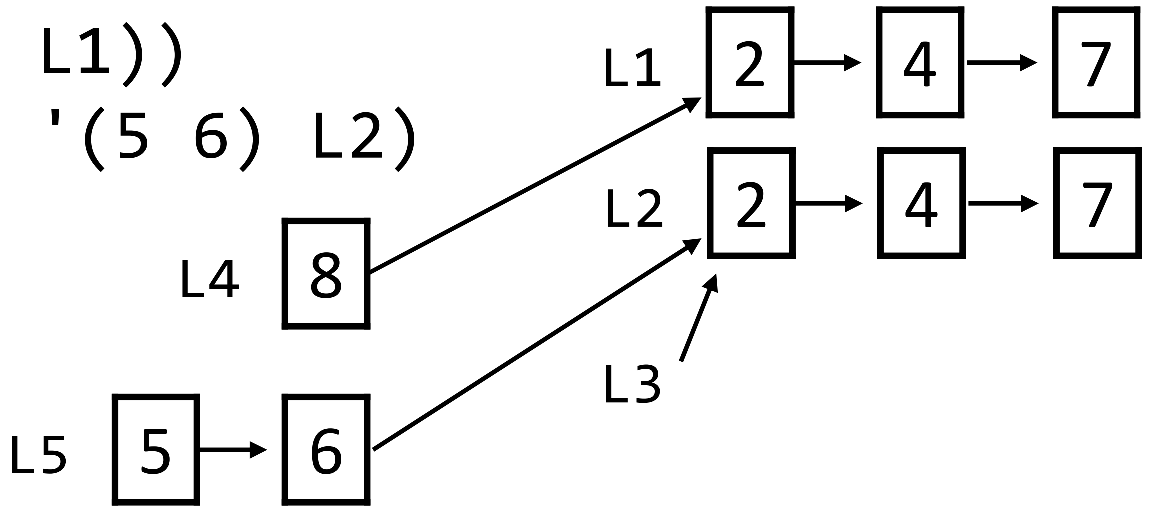
```
(define L1 '(2 4 7))
(define L2 '(2 4 7))
(define L3 L2)
```



- (eq? ***expr1 expr2***) ; reference/ptr comparison
- (eqv? ***expr1 expr2***) ; compares values/numbers
- (= ***expr1 expr2***) ; like eqv; numbers only
- (equal? ***expr1 expr2***) ; deep equality test
  - Which are true for L1 and L2? L3?

Sharing between lists

```
(define L4 (cons 8 L1))
(define L5 (append '(5 6) L2))
```

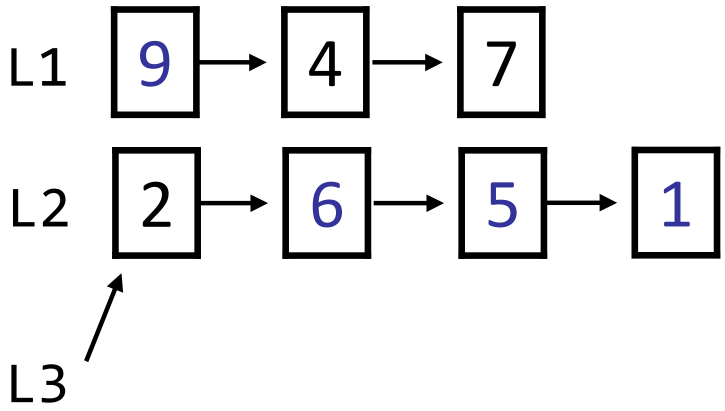


- Which of the following are true?

```
(eq? L4 '(8 2 4 7))
(equal? L5 '(5 6 2 4 7))
(equal? L1 (cdr L4))
(eq? L1 (cdr L4))
(equal? L2 (cddr L5))
(eq? L2 (cddr L5))
(eq? L3 (cddr L5))
```

Mutating lists

(set-car! ***list expr***)
(set-cdr! ***list expr***)



- these procedures mutate the contents of lists (!)
- any reference to that list will see the change

```
(set-car! L1 9)
(set-cdr! L2 '(6 5 1))
```

(`set-car!` and `set-cdr!` are disabled in "Pretty Big" Scheme)

Mutable lists

```
(mcons expr mutableList)
(mcar mutableList)
(mcdr mutableList)
(set-mcar! mutableList expr)
(set-mcdr! mutableList expr)
```

- Scheme has a separate mutable list type that you can use to explicitly create a list that can be modified
  - can build up a list by calling `mcons` with `null`
  - mutable lists display on the interpreter with `{...}`

(mutable lists are not allowed on our homework)

Memoization

Exercise

- Define a procedure `count-factors` that accepts an integer parameter and returns how many factors it has.
  - Possible solution:

```
(define (count-factors n)
    (length (filter (lambda (x) (= 0 (modulo n x)))
                    (range 1 n))))
```

  - Problem: slow for large values; "forgets" after each call

```
> (count-factors 999990)
48       ; takes 4-5 seconds
> (count-factors 999990)
48       ; takes 4-5 seconds, AGAIN!
```

Memoization

- **memoization**: Optimization technique of avoiding re-calculating results for previously-processed function calls.
  - often uses a **cache** of previously computed values

- General algorithmic pattern:

```
function compute(param):
    if I have never computed the result for this value of param before:
        compute the result for param.
        store (param, result) into cache data structure.
        return result.
    else      // I have computed this result before; don't re-compute
        look up (param, result) in cache data structure.
        return result.
```

Memoization w/ association lists

- a natural structure to cache prior calls is a *map*
  - recall: Scheme implements maps as *association lists*

```
> (define phonebook (list '(Marty 6852181)
     '(Stuart 6859138) '(Jenny 8675309)))
> (assoc 'Stuart phonebook)
(Stuart 6859138)
> (cdr (assoc 'Jenny phonebook))  ; get value
8675309
```

  - we'll remember results of past calls to `count-factors` by storing them in a (mutating) association list

Memoizing count-factors code

```
; cache of past calls as (n . count) pairs; initially empty
(define cache null)

(define (count-factors n)
  (define (divides? x) (= 0 (modulo n x)))
  ; look up n in the cache (see if we computed it before)
  (let ((memory (assoc n cache)))
    (if memory   ; if n is in cache, return cached value.
        (cdr memory)
                 ; else, count the factors...
        (let ((count (length (filter divides? (range 1 n)))))
          ; store them into the cache...
          (set! cache (cons (cons n count) cache))
          ; and return the result.
          count))))
```

Problem: undesired global cache

- the `cache` is a global variable
  - can be seen (or modified!) by other code

- solution: define it locally
  - to do this properly, we must define `count-factors` using an inner helper and local inner cache
  - `count-factors` is set equal to its own helper
    - bizarre, but ensures proper *closure* over the local cache

Improved count-factors code

```
(define count-factors
  (let ((cache null))  ; local cache; initially empty

    ; inner helper that has access to the local cache
    (define (helper n)
      (define (divides? x) (= 0 (modulo n x)))

      ; look up n in the cache (see if we computed it before)
      (let ((memory (assoc n cache)))

        (if memory   ; if n is in cache, return cached value.
            (cdr memory)

            ; else, count the factors...
            (let ((count (length (filter divides? (range 1 n)))))
              ; store them into the cache...
              (set! cache (cons (cons n count) cache))

              ; and return the result.
              count))))
    helper))  ; return helper; sets count-factors equal to helper
```