CS61A Lecture 25

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Review Analyzing Evaluator

- What procedures look like
- What the output of `analyze` was
- Fact: The body of a `lambda` gets analyzed!
- We can give names to analyzed `lambda`s

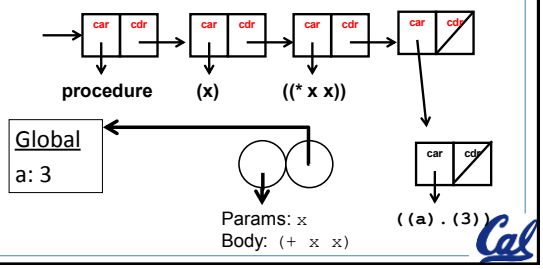
What gets returned by mc-eval? (not analyzing eval)

```
STk> (mc-eval '(lambda (x) (* x x)) '((a) 3)))
```

A. `(procedure (x) ((* x x)) ((a) 3)))`
B. `(procedure (x) (* x x) ((a) 3)))`
C. `(lambda (x) ((* x x)) ((a) 3)))`
D. `(lambda (x) (* x x) ((a) 3)))`
E. Other (or no clue!)

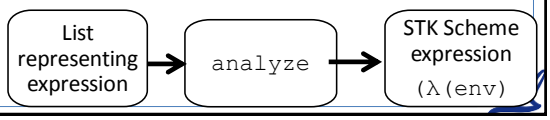
REVIEW What is a procedure?

```
STk> (mc-eval '(lambda (x) (* x x)) '((a) 3)))
(procedure (x) ((* x x)) ((a) 3)))
```



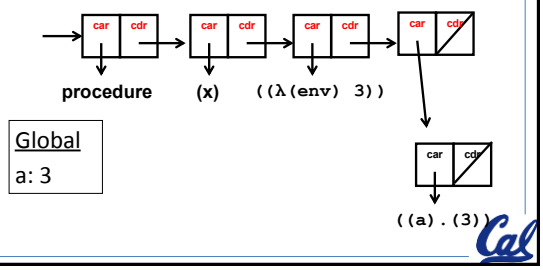

```
(define (mc-eval exp env)
  (cond
     ((self-evaluating? exp) exp) ...
(define (analyze exp)
  (cond
     ((self-evaluating? exp)
                (analyze-self-evaluating exp))...

(define (analyze-self-evaluating exp)
  (lambda (env) exp))
```



The body of a lambda gets analyzed!

```
STk> (mc-eval '(lambda (x) 3) '((a) 3)))
(procedure (x) ((λ (env) 3)) ((a) 3)))
```



(analyze '(if #t 3 4))

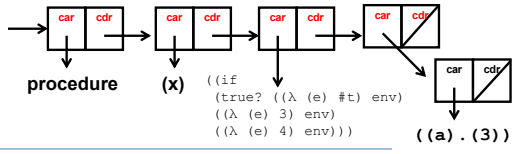
```
(define (analyze exp)
  (cond ((self-evaluating? exp)
                (analyze-self-evaluating exp))
        ((if? exp) (analyze-if exp))...

(define (analyze-if exp)
  (let ((pproc (analyze (if-predicate exp)))
        (cproc (analyze (if-consequent exp)))
        (aproc (analyze (if-alternative exp))))
    (lambda (env)
      (if (true? (  (λ(e) #t)   env))
          (  (λ(e) 3)           env)
          (  (λ(e) 4)           env)))))
```

The body of a lambda gets analyzed!

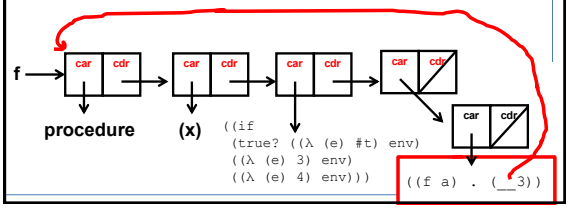
```
STk>(mc-eval '(lambda (x) '(if #t 3 4))'(((a) 3)))
(procedure (x) (                    ) (((a) 3)))
```

```
(if
 (true? ((λ (e) #t) env)
 ((λ (e) 3) env)
 ((λ (e) 4) env))
```



The body of a lambda gets analyzed!

```
STk>(mc-eval '(define f
                    (lambda (x)
                        '(if #t 3 4))
                '(((a) 3)))
```

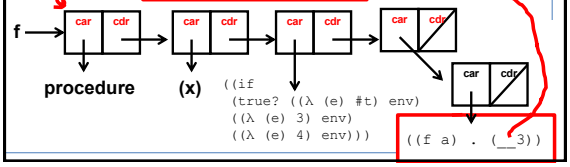


The body of a lambda gets analyzed!

```
STk>(mce)
;;; M-Eval input:
(f 1)
```

```
(define (mc-eval exp env)
  ((analyze exp) env))
```

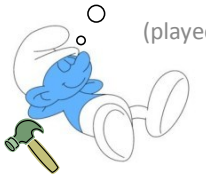
If we call f many times – we save time!



I'll get the "actual value" of arguments once they're ***really*** needed

Lazy Evaluator

(played by Lazy Smurf)

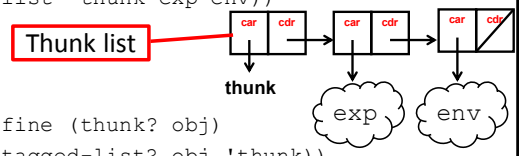


Understanding Lazy [eval/smurf]

- Thunk ADT
  - A Thunk List – not a real scheme thunk
- Storing the environment
  - If we're going to delay the evaluation of arguments we need to keep track of the environment where they *should* be evaluated.
- Delay arguments to user-defined procedures!
  - Not to primitive procedures

Thunk ADT (not a STk *REAL* thunk!)

```
(define (delay-it exp env)
  (list 'thunk exp env))
```

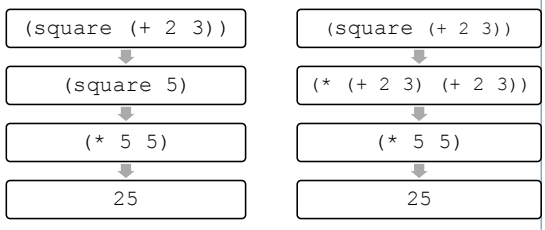



```
(define (thunk? obj)
  (tagged-list? obj 'thunk))
(define (thunk-exp thunk) (cadr thunk))
(define (thunk-env thunk) (caddr thunk))
```

exp is(A) list representing an expression or (B) REAL Scheme?

What would lazy [eval/smurf] do?

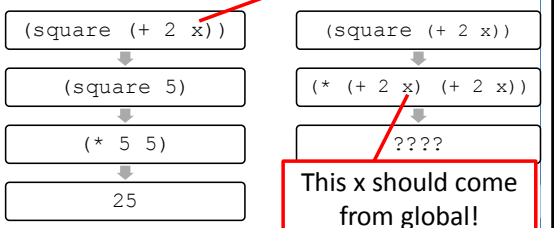
```
STk> (define (square x) (* x x))
STk> (square (+ 2 3))
```



A. Applicative Order B. *Normal* Order

```
STk> (define x 3)
STk> (define (square x) (* x x))
STk> (square (+ 2 x))
```

BEFORE we call square: figure out arguments!

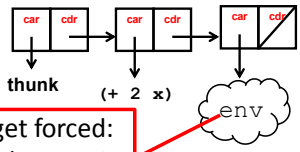


This x should come from global!

Applicative Order *Normal* Order

If we're going to `delay-it` we need to keep track of the environment!

```
(define (delay-it exp env)
  (list 'thunk exp env))
```



When I get forced: evaluate the `exp` in this environment

How (regular) mc-eval evaluated args?!?

```
(define (mc-eval exp env)
  (cond ...
    ((application? exp)
      (mc-apply (mc-eval (operator exp) env)
        (list-of-values (operands exp) env)))

(define (list-of-values exps env)
  (if (no-operands? exps)
    '()
    (cons
      (mc-eval (first-operand exps) env)
      (list-of-values (rest-operands exps) env))))
```

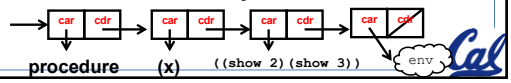
How lazy [smurf] mc-eval evaluates args?!?

```
(define (mc-eval exp env)
  (cond ...
    ((application? exp)
      (mc-apply (mc-eval (operator exp) env)
        (list-of-values (operands exp) env)))
```

We're going to change the range of `mc-eval` so we'll have to change this too.

Regular mc-apply

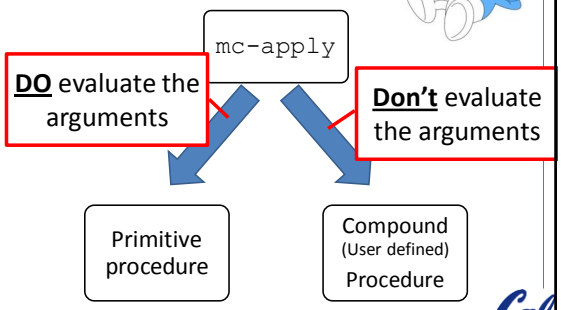
```
(define (mc-apply procedure arguments)
  (cond ((primitive-procedure? procedure)
         (apply-primitive-procedure procedure arguments))
        ((compound-procedure? procedure)
         (eval-sequence
           (procedure-body procedure)
           (extend-environment
             (procedure-parameters procedure)
             arguments
             (procedure-environment procedure))))
        (else (error "Unknown" procedure))))
```



This is the lazy version – how many changes? A. 1 B. 2 C. 3 D. 4

```
(define (mc-apply procedure arguments env)
  (cond ((primitive-procedure? procedure)
         (apply-primitive-procedure
          procedure
          (list-of-arg-values arguments env)))
        ((compound-procedure? procedure)
         (eval-sequence
          (procedure-body procedure)
          (extend-environment
           (procedure-parameters procedure)
           (list-of-delayed-args arguments env)
           (procedure-environment procedure))))
        (else (error "Unknown" procedure))))
```

The lazy mc-apply



In the lazy version Where do arguments get delayed?

A. In `mc-eval`
B. In `mc-apply`
C. In both
D. In neither
E. ???

In the *REGULAR* version Where do arguments get evaluated?

A. In `mc-eval`
B. In `mc-apply`
C. In both
D. In neither
E. ???

In the lazy version Where do arguments get evaluated?

A. In `mc-eval`
B. In `mc-apply`
C. In both
D. In neither
E. ???

How many of these are different in Normal vs. Applicative order?

(invent one example that isn't and one that is)

```
STk> 3
3
STk> (define x 3)
x
STk> x
3
STk> 'x
x
```

```
STk> (set! x 4)
okay
STk> (if #t 3 4)
3
STk> (lambda (x) x)
#[closure arglist=(x) 7ff27c98]
STk> (begin 2 3)
3
```

A. 0 B. 1-2 C. 3-5 D. 6-8 E.??

```
(define (mc-eval exp env)
  (cond
    ((self-evaluating? exp)...
    ((variable? exp)...
    ((quoted? exp) ...
    ((assignment? exp) ...
    ((definition? exp) ...
    ((if? exp) ...
    ((lambda? exp) ...
    ((begin? exp) ...
    ((cond? exp) ...
    ((application? exp) ...
    (else (error "what?"))))
```

How many times might we be lazy (and delay stuff)?

A. 0
B. 1-2
C. 3-5
D. 6-8
E.??

A problem with delaying stuff

```
STk> (load "lazy.scm")
okay
STk> (define g-env (setup-environment))
g-env
STk> (mc-eval '((lambda (x) x) (+ 2 3)) g-env)
(thunk (+ 2 3) env)
```

User-defined procedure: **Don't** evaluate the arguments

Remember – we delayed args to compound procedures (user-defined)

```
(define (mc-apply procedure arguments env)
  (cond ((primitive-procedure? procedure)
         (apply-primitive-procedure
          procedure
          (list-of-arg-values arguments env)))
        ((compound-procedure? procedure)
         (eval-sequence
          (procedure-body procedure)
          (extend-environment
           (procedure-parameters procedure)
           (list-of-delayed-args arguments env)
           (procedure-environment procedure))))
        (else (error "Unknown" procedure))))
```

What can be returned by the lazy `mc-eval` function

What can be ret

A. Values
B. Lists
C. Thunk ADTs
D. All of the above
E. None of the above

What happens here?

```
STk> (load "lazy.scm")
okay
STk> (define g-env (setup-environment))
g-env
STk> (mc-eval '((lambda (x) (+ 1 x)) (+ 2 3)) g-env)
```

What is returned?

a. (thunk (+ 1 5) env)
b. (thunk (+ 1 (+ 2 3)) env)
c. 6
d. Something else
e. ???

SOLUTION

If the driver-loop needs to print it – make sure you haven't been TOO lazy.

```
(define (driver-loop)
  (prompt-for-input input-prompt)
  (let ((input (read)))
    (let ((output
           (actual-value input the-global-environment)))
      (announce-output output-prompt)
      (user-print output)))
  (driver-loop))
```

This was: **mc-eval**

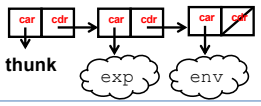
mc-eval might return a delayed argument from a compound procedure

actual-value

```
(define (actual-value exp env)
  (force-it (mc-eval exp env)))

(define (force-it obj)
  (if (thunk? obj)
      ??
      (thunk-exp obj)
      (thunk-env obj))
      obj))
```

A. (mc-eval
B. (actual-value



Example of why we call actual-value

```
STk> (load "lazy.scm")
okay
STk> (define g-env (setup-environment))
g-env
STk> (mc-eval
     '((lambda (x) x)
       ((lambda (y) y)
        (+ 2 3)))
     g-env)
(thunk ((lambda (y) y) (+ 2 3)) env)
```

```
(define (mc-eval exp env)
  (cond
    ((self-evaluating? exp)...
     ((variable? exp)...
     ((quoted? exp) ...
     ((assignment? exp) ...
     ((definition? exp) ...
     ((if? exp) ...
     ((lambda? exp) ...
     ((begin? exp) ...
     ((cond? exp) ...
     ((application? exp) ...
     (else (error "what?"))))
```

What happens if we pass a Thunk ADT as exp?

A. errors
B. application
C. lambda
D. self-eval.
E.??

if's need actual values!

```
(define (eval-if exp env)
  (if (true?
              (actual-value
                   (if-predicate exp)
                   env))
      (mc-eval (if-consequent exp) env)
      (mc-eval (if-alternative exp) env)))
```

mc-eval sometimes returns Thunk ADTs

Summary & Additional Notes

- Thunk ADTs could also be memoized
- We delayed arguments to compound procedures
  - Compound procedures are defined by the user
- We didn't delay arguments to primitive procedures
- We made sure we had the actual value to print it
- Ifs needed REAL values