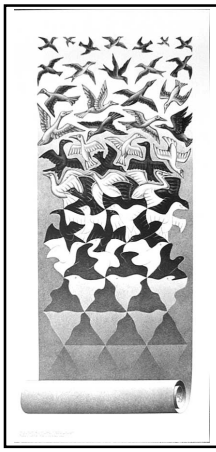

Lecture 19: Programming with State

CS150: Computer Science
University of Virginia
Computer Science

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Notices

- Today: normal lab hours (4-5:30pm)
- Thursday's lab hours will be 5-7pm (instead of normally scheduled times)
- Spring Break – there will not be normally scheduled lab hours or office hours between March 3 and March 10. Normal lab hours resume Sunday, March 11.
- Exam 1 will be returned at end of today's class
- Schedule for rest of semester is updated on the course web (www.cs.virginia.edu/schedule/)

From Lecture 3:

Evaluation Rule 2: Names

If the expression is a *name*, it evaluates to the value associated with that name.

```
> (define two 2)
> two
2
```


Names and Places

- A name is not just a value, it is a **place** for storing a value.
- **define** creates a new place, associates a name with that place, and stores a value in that place

```
(define x 3)
```

x: 3

Bang!

set! ("set bang") changes the value associated with a place

```
> (define x 3)
> x
3
> (set! x 7)
> x
7
```

x: 7

set! should make you nervous

```
> (define x 2)
> (nextx)
3
> (nextx)
4
> x
4
```

Before **set!** all procedures were functions (except for some with side-effects). The value of (f) was the same every time you evaluate it. Now it might be different!

Defining nextx

```
(define (nextx)
  (set! x (+ x 1))
  x)
```

syntactic sugar for

```
(define nextx
  (lambda ()
    (begin
      (set! x (+ x 1))
      x)))
```


Evaluation Rules

```
> (define x 3)
> (+ (nextx) x)
7
or 8
> (+ x (nextx))
9
or 10
```

DrScheme evaluates application subexpressions left to right, but Scheme evaluation rules allow any order.

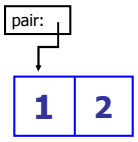
set-car! and **set-cdr!**

(set-car! *p v*)
Replaces the car of the cons *p* with *v*.

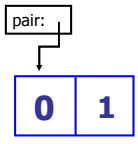
(set-cdr! *p v*)
Replaces the cdr of the cons *p* with *v*.

These should scare you even more then set!!


```
> (define pair (cons 1 2))
> pair
(1 . 2)
```




```
> (define pair (cons 1 2))
> pair
(1 . 2)
> (set-car! pair 0)
> (car pair)
0
> (cdr pair)
2
> (set-cdr! pair 1)
> pair
(0 . 1)
```



map

Functional Solution: A procedure that takes a procedure of one argument and a list, and returns a list of the results produced by applying the procedure to each element in the list.

```
(define (map proc lst)
  (if (null? lst) null
      (cons (proc (car lst))
            (map proc (cdr lst)))))
```

Imperative Solution

```
(define (map proc lst)
  (if (null? lst) null
      (cons (proc (car lst))
            (map proc (cdr lst)))))
```

A procedure that takes a procedure and list as arguments, and ***replaces*** each element in the list with the value of the procedure applied to that element.

```
(define (map! f lst)
  (if (null? lst) (void)
      (begin
        (set-car! lst (f (car lst)))
        (map! f (cdr lst)))))
```


Programming with Mutation

Imperative

```
> (map! square (intsto 4))
> (define i4 (intsto 4))
> (map! square i4)
> i4
(1 4 9 16)
```

Functional

```
> (define i4 (intsto 4))
> (map square i4)
(1 4 9 16)
> i4
(1 2 3 4)
```


Mutation Changes Everything!

- We can no longer talk about the "value of an expression"
  - The value of a give expression can change!
  - We need to talk about "the value of an expression in an *execution environment*"
- The order in which expressions are evaluated now matters

Why Substitution Fails?

```
> (define (nextx) (set! x (+ x 1)) x)
> (define x 0)
> ((lambda (x) (+ x x)) (nextx))
2
```

Substitution model:

```
(+ (nextx) (nextx))
(+ (begin (set! x (+ x 1)) x) (begin (set! x (+ x 1)) x))
(+ (begin (set! 0 (+ 0 1)) 0) (begin (set! 0 (+ 0 1)) 0))
(+ 0 0)
0
```

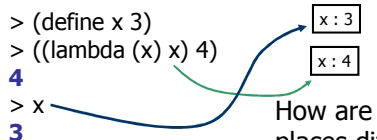

Names and Places

- A name is a **place** for storing a value.
- **define** creates a new place
- **cons** creates two new places, the **car** and the **cdr**
- **(set!** *name expr***)** changes the value in the place *name* to the value of *expr*
- **(set-car!** *pair expr***)** changes the value in the **car** place of *pair* to the value of *expr*

Lambda and Places

- (lambda (x) …) also creates a new place named x
- The passed argument is put in that place

```
> (define x 3)
> ((lambda (x) x) 4)
4
> x
3
```

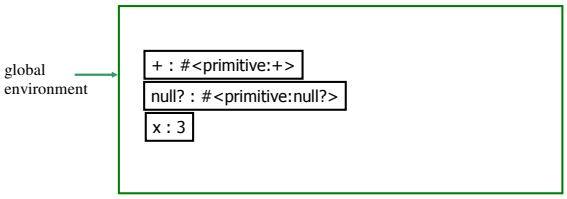


How are these places different?

Location, Location, Location

- Places live in **frames**
- An **environment** is a frame and a pointer to a parent environment
- All environments except the global environment have exactly one parent environment, global environment has no parent
- Application creates a new environment

Environments



The global environment points to the outermost frame. It starts with all Scheme primitives.

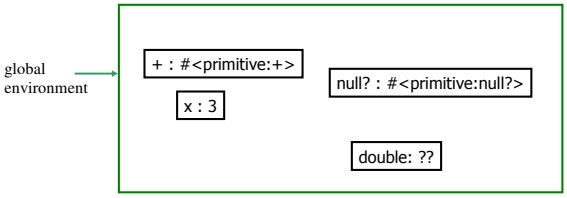
> (define x 3)

Evaluation Rule 2: Names

A *name* expression evaluates to the value associated with that name.

To find the value associated with a name, look for the name in the frame associated with the evaluation environment. If it contains a place with that name, the value of the name expression is the value in that place. If it doesn't, the value of the name expression is the value of the name expression evaluated in the parent environment if the current environment has a parent. Otherwise, the name expression evaluates to an error (the name is not defined).

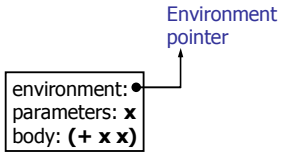
Procedures



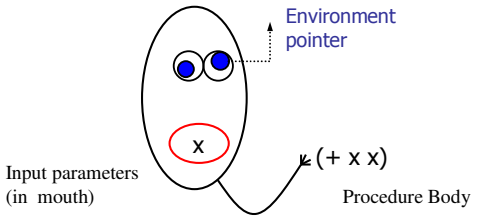
> (define double (lambda (x) (+ x x)))

How to Draw a Procedure

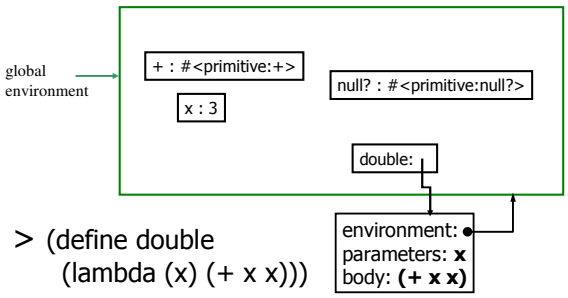
- A procedure needs **both code and an environment**
  - We'll see why soon
- We draw procedures like this:



How to Draw a Procedure (for artists only)



Procedures



> (define double
(lambda (x) (+ x x)))

Application

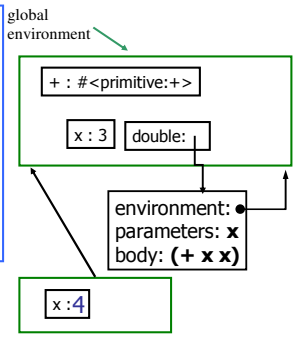
- Old rule: (Substitution model)

Apply Rule 2: Constructed Procedures. To apply a constructed procedure, **evaluate** the body of the procedure with each formal parameter replaced by the corresponding actual argument expression value.

New Application Rule 2:

1. Construct a new environment, whose parent is the environment to which the environment pointer of the applied procedure points.
2. Create a place in that frame for each parameter containing the value of the corresponding operand expression.
3. Evaluate the body in the new environment. Result is the value of the application.

1. Construct a new environment, parent is procedure's environment pointer
2. Make places in that frame with the names of each parameter, and operand values
3. Evaluate the body in the new environment



> (double 4)
8

(+ x x)

Charge WAHOO! Auctions

- Now: Return Exam 1
  - My stack of exams is sorted by first name (as you wrote it on your exam)
  - What is a good algorithm for sorting you all in order to hand back the exams?
- PS5: You know everything you need to do it after today, so start early!
- Friday: Error Messages, Golden Ages, Sex, Politics, and Religion