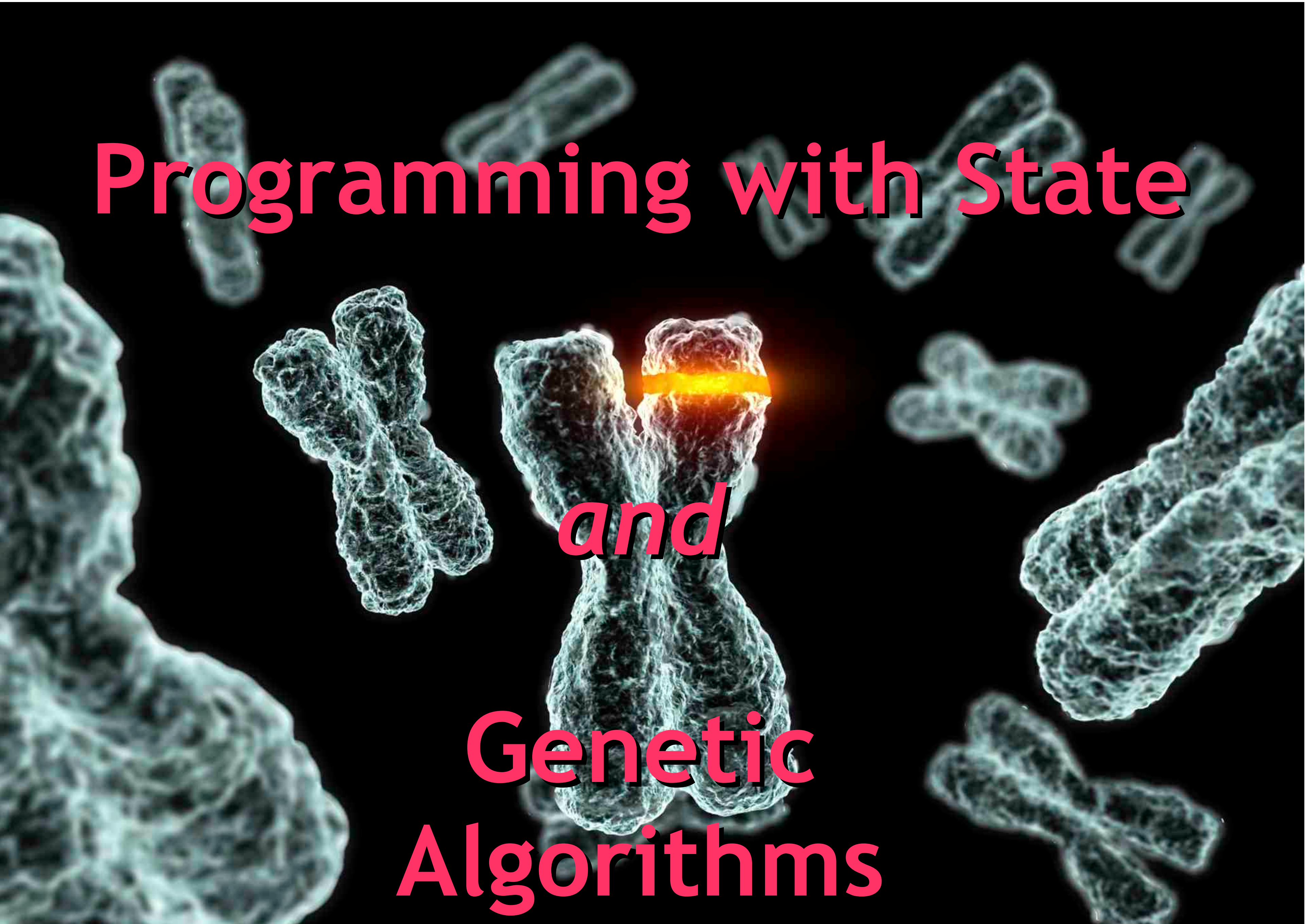
Programming with State

and

Genetic Algorithms



One-Slide Summary

- The **substitution model** for evaluating Scheme does not allow us to reason about mutation. In the **environment model**:
- A **name** is a **place** for storing a value. `define`, `mcons`, `cons` and function application create places. **`set!`** changes the value in a place.
- Places live in **frames**. An **environment** is a frame and a pointer to a **parent frame**. The **global environment** has no parent.
- To **evaluate** a name, walk up the frames until you find a definition.
- Functional and imperative procedures may have **different asymptotic costs**.

Outline

- Functional vs. Imperative
- Names and Places
- Environment Model practice
- Cost computation practice
- Undergrad research

Functional vs. Imperative

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

Imperative Solution

```
(define (list-map proc lst)
  (if (null? lst) null
      (cons (proc (car lst))
            (list-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 (mlist-map! f lst)
  (if (null? lst) (void)
      (begin
        (set-mcar! lst (f (mcar lst)))
        (mlist-map! f (mcdr lst)))))
```

Programming with Mutation

Imperative

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

Functional

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

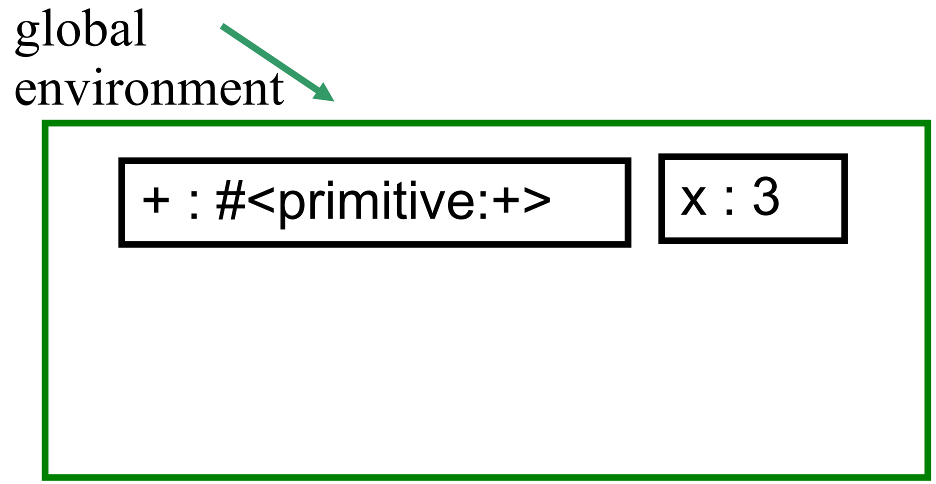
Names and Places

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

New Application Rule:

1. **Construct a new environment**, whose parent is the environment to which the environment pointer of the applied procedure points.
2. **Create places** 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.

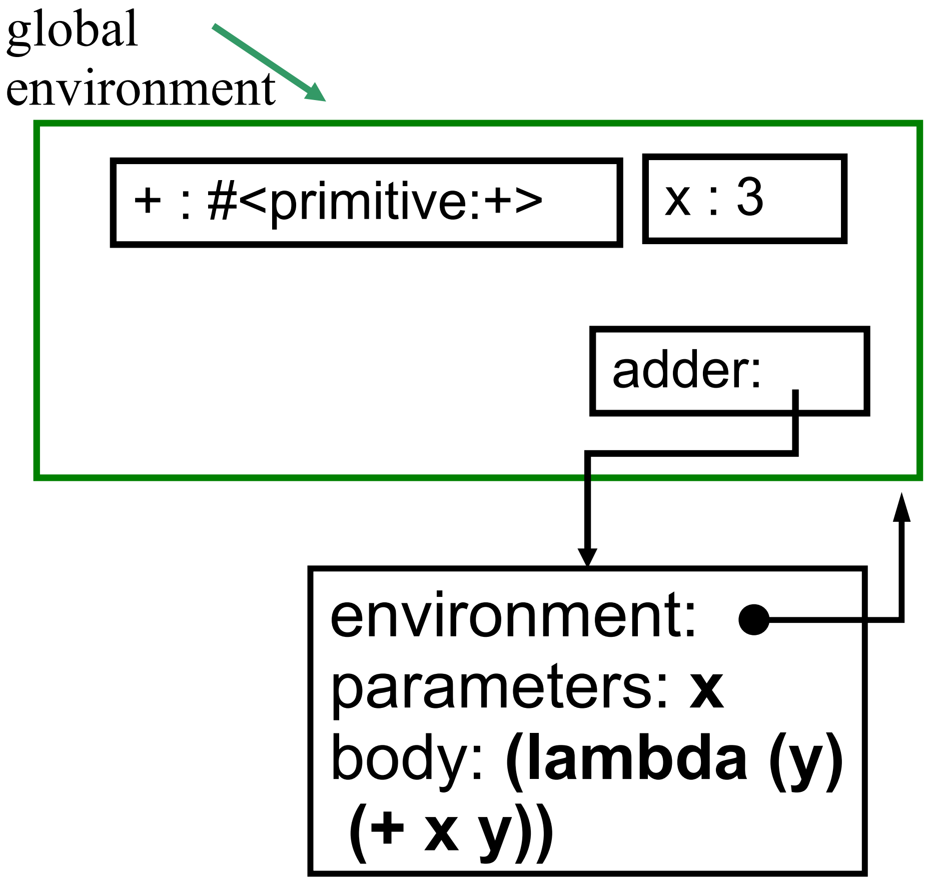
1. Construct a new environment, parent is procedure's environment pointer
2. Make places in that frame with the names of each parameter, and operand values
3. Evaluate the body in the new environment




```
> (define x 3)
```

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

```
> (define x 3)
> (define (adder x)
     (lambda (y) (+ x y))))
```



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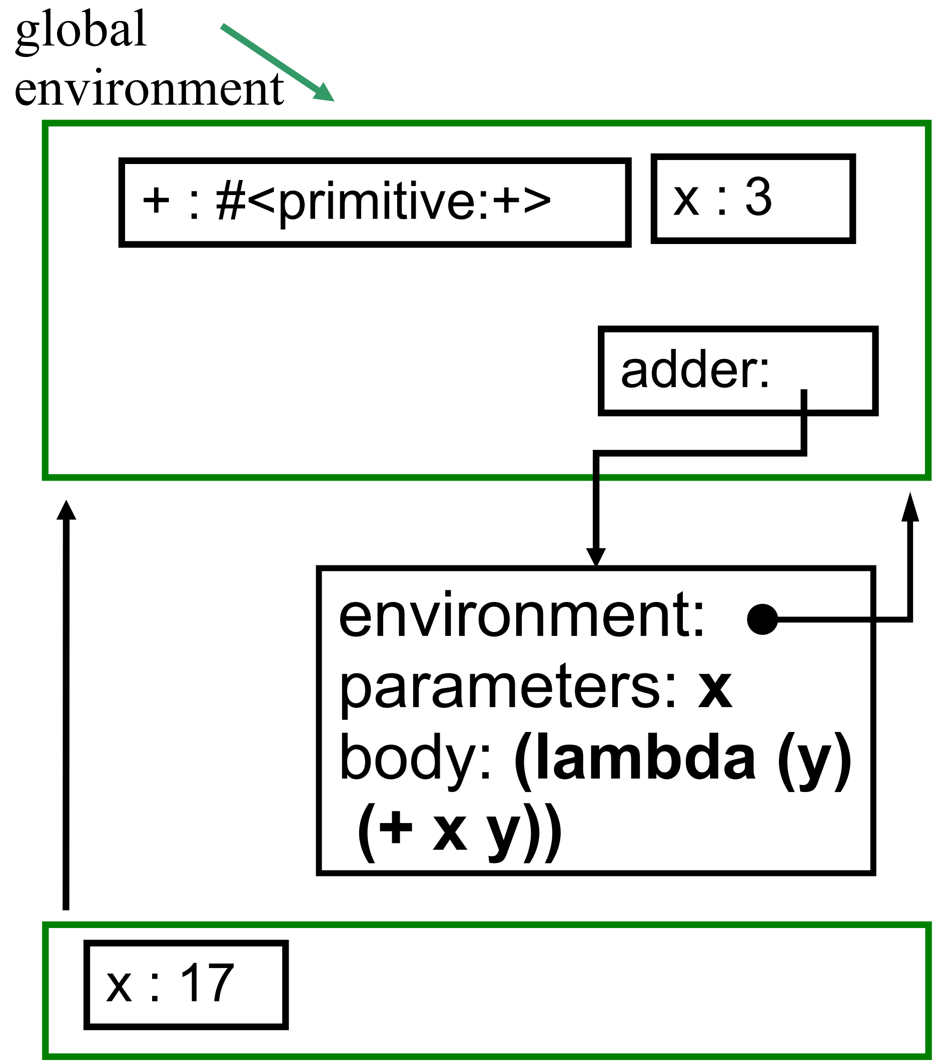

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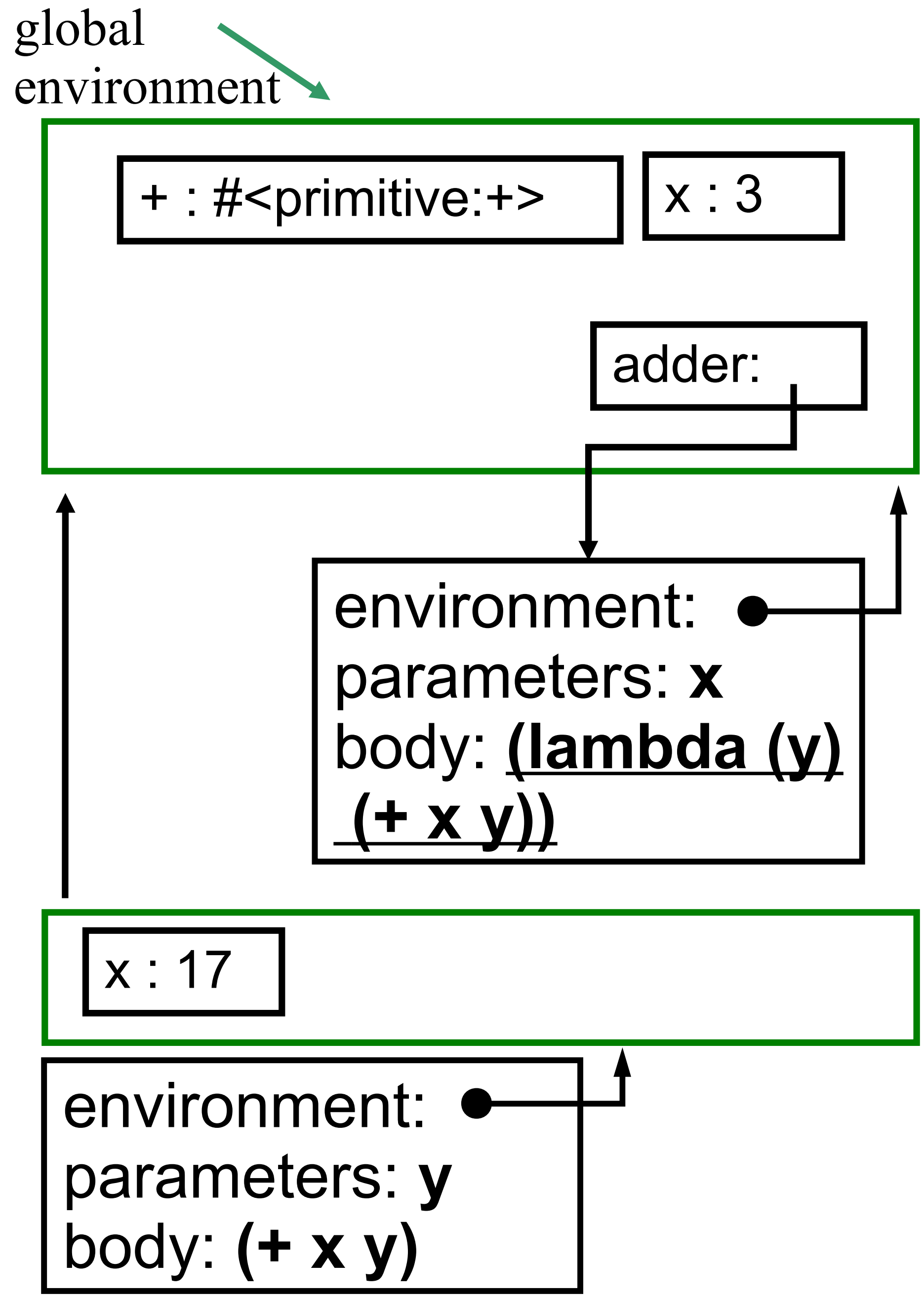

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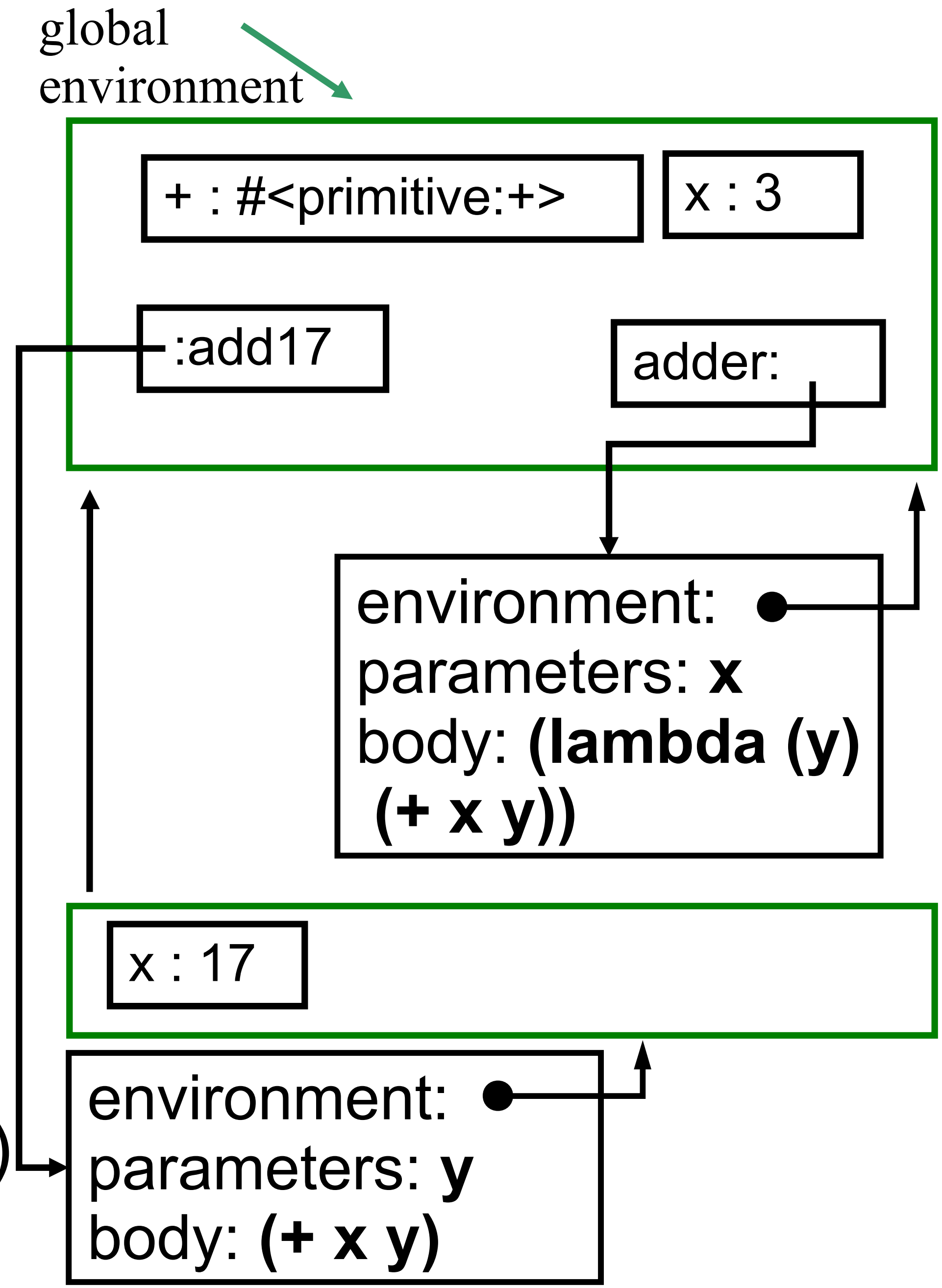


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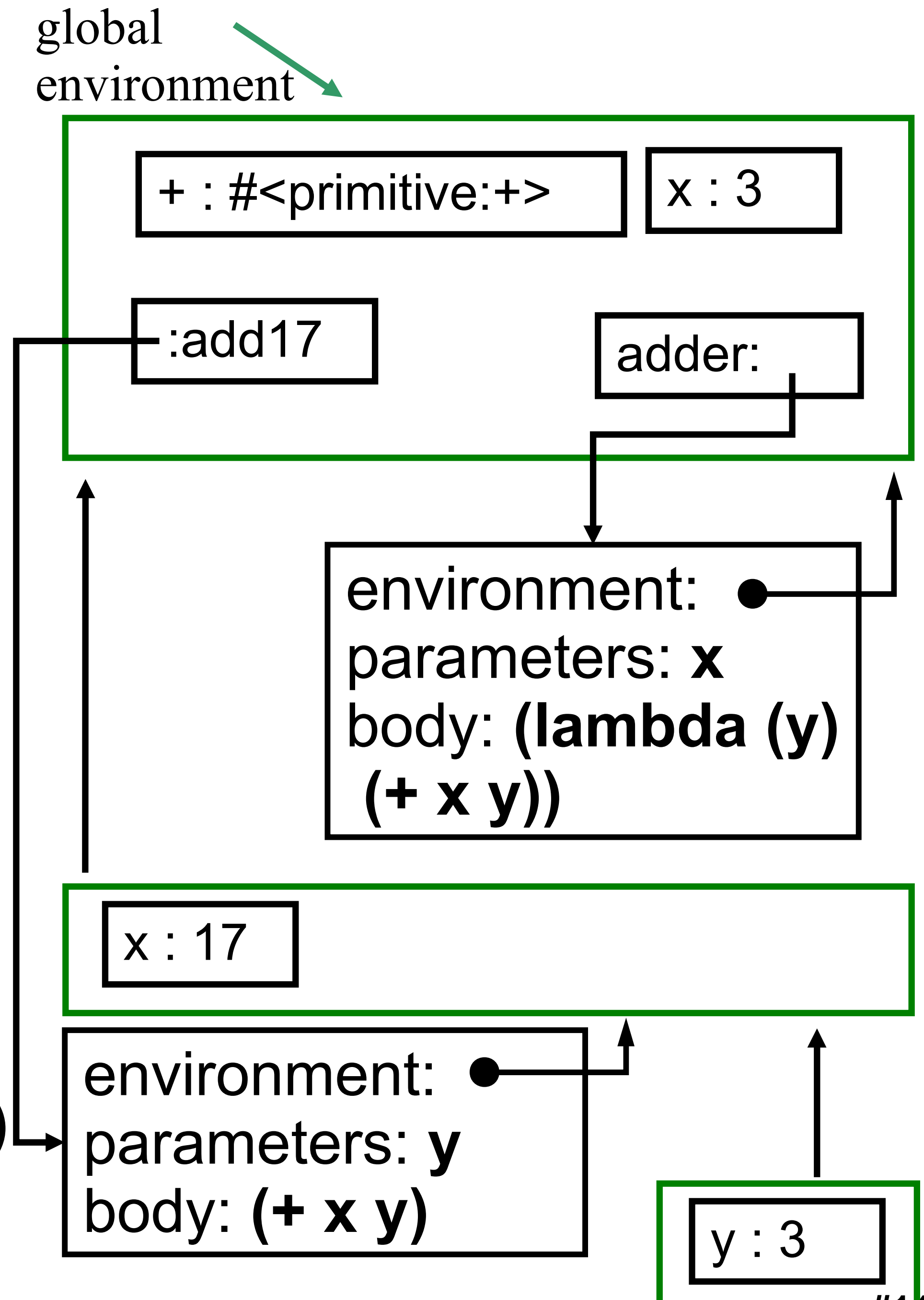

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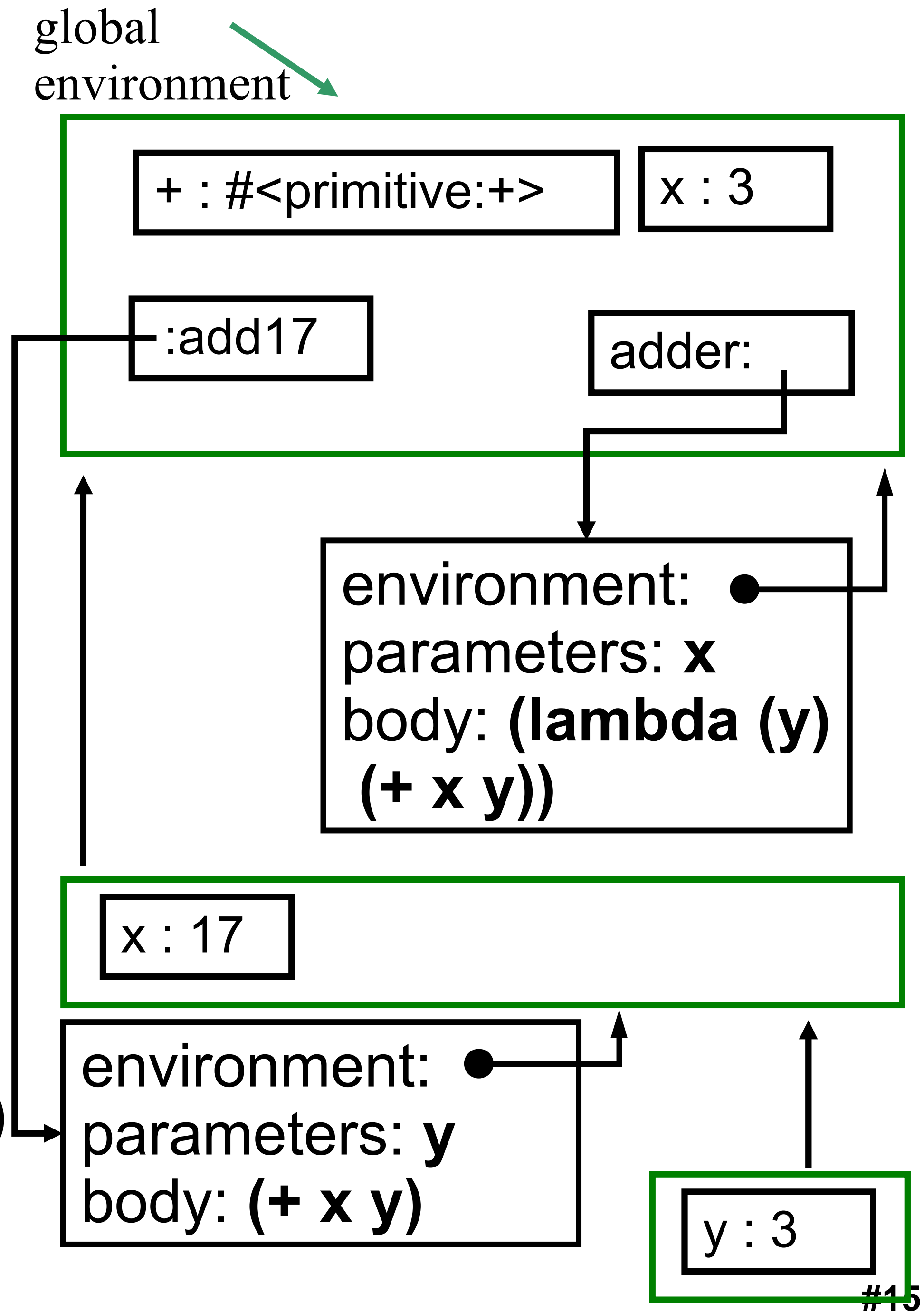
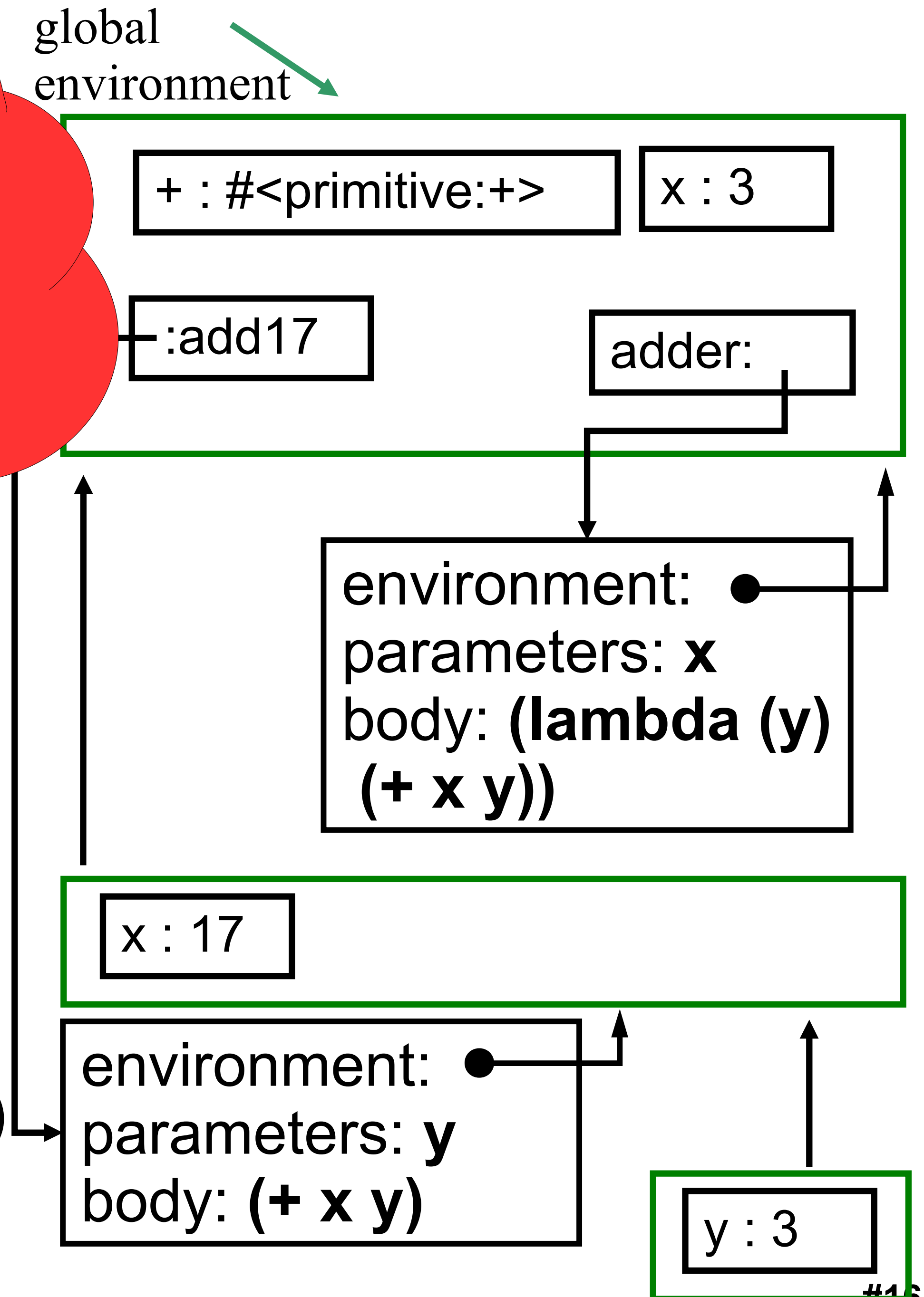


1. Constr

This answers the thought question on Slide #22 of Last Lecture!

3. Evaluate dy in the new environment

```
> (define x 3)
> (define (adder x)
      (lambda (y) (+ x y))))
> (define add17 (adder 17))
> (add17 3)
```



Functional vs. Imperative Costs

```
(define (l-map f p)
 (if (null? p) null
  (cons (f (car p))
   (l-map f (cdr p)))))
```

- Running Time: O(N)
  - where N is (length p)
  - Assuming f in O(1)
- Memory Use: O(N)
  - N new cons cells

```
(define (ml-map! f p)
 (if (null? p) (void)
  (begin
   (set-mcar! p (f mcar p))
   (ml-map! f (mcdr p)))))
```

- Running Time: O(N)
  - Also N recursive calls with O(1) work each
- Memory Use: O(1)
  - No new cons cells

Functional vs. Imperative Costs

```
(define (list-append p q)
 (if (null? p) q
  (cons (car p) (list-append (cdr p) q))))
```

- Running Time: O(p); p = (length p)
- New Cons Cells: O(p)

```
(define (mlist-append! p q)
 (if (null? p) (error "append to empty list!")
  (if (null? (mcdr p)) (set-mcdr! p q)
   (mlist-append! (mcdr p) q))))
```

- Running Time: O(p), New Cons Cells: Zero

mlist-append! in action

```
> (define (mlist-append! p q)
 (if (null? p) (error “append to empty list!”)
  (if (null? (mcdr p)) (set-mcdr! p q)
   (mlist-append! (mcdr p) q))))
> (define animals (mcons "ant" (mcons "bat" null)))
> (define colors (mcons "red" (mcons "green" null)))
> (mlist-append! animals colors)
> animals
```

? ? ?

```
> colors
```

? ? ?

mlist-append! in action

```
> (define (mlist-append! p q)
 (if (null? p) (error “append to empty list!”)
  (if (null? (mcdr p)) (set-mcdr! p q)
   (mlist-append! (mcdr p) q))))
> (define animals (mcons "ant" (mcons "bat" null)))
> (define colors (mcons "red" (mcons "green" null)))
> (mlist-append! animals colors)
> animals
{"ant" "bat" "red" "green"}
> colors
{"red" "green"}
```

Open-Ended Question

- You're designing cars.
- Each of your designs has various properties:
  - High or low fuel efficiency, spacious or cramped interior, manual or automatic transmission, high or low purchase price, etc.
- You can also run a few focus groups or trial sales:
  - To see how many people will buy a given design.
- ***How do you make the best-selling design?***

Genetic Algorithms

- Search Strategy based on biological evolution
  - Find X that maximizes P(X)
  - Find CarDesign maximizing Sales(CarDesign)
- Idea:
  - Represent car design as genome (string)
    - "LSMH" = "low fuel efficiency, spacious, manual, ..."
  - Maintain a **population** of variant genomes
  - Apply a random **mutation** operator to them
  - The **fittest** individuals survive and mate
  - Process repeats with a new generation

Mutation and Crossover

- Mutation:
  - "**LSMH**" might become "**LCMH**"
- Crossover:

  "**LSMH**"

  + "**LCAL**"

  = "**LSAL**" + "**LCMH**"
- Fitness:
  - Turn your genotype into a phentotype (i.e., build a model car from your design) and evaluate it (i.e., hire a focus group, test sales, etc.)

Genetic Algorithm Successes

- Creation of a **soccer-playing program** that ranked in the middle of the field of 34 human-written programs in the Robo Cup 1998 competition
- Synthesis of an **electronic thermometer**
- Automated **Re-Invention of Six Patented** Optical Lens Systems using Genetic Programming
- Towards Better than Human Capability in **Diagnosing Prostate Cancer** Using Infrared Spectroscopic Imaging
- Scaffolding for Interactively **Evolving Novel Drum Tracks** for Existing Songs

Unrelated Question

- So Genetic Algorithms are a heuristic approach for making small random changes to something until, by chance, you make some external judge happy.

- Totally unrelated question. How do your friends pass Automatic Adjudication programming assignments in this class?

Automated Program Repair

- On December 31st, 2008, MS Zune 30 music players died
- Microsoft had sold 1.2 million
- Problem: infinite loop in a recursive computation converting days to years
  - Bug shows up on last day of each leap year
- Microsoft's recommendation was to drain the Zune's battery and reset it
- **Our genetic programming approach fixes the source code in 42 seconds.**

The Bug

```
(define (days-to-years day year)
 (if (<= day 365)
  year
  (if (is-leap-year? year)
    (if (> day 366)
        (days-to-years (- day 366) (+ year 1))
        (days-to-years day year))
    (days-to-years (- day 365) (+ year 1)))))
```

Try These Tests:
(days-to-years 300 2008)
(days-to-years 700 2008)
(days-to-years 366 2008)

The Fix

```
(define (days-to-years day year)
 (if (<= day 365)
  year
  (if (is-leap-year? year)
    (if (> day 366)
         (days-to-years (- day 366) (+ year 1))
         (days-to-years (- day 366) year))
    (days-to-years (- day 365) (+ year 1)))))
```

Automated Program Repair

- On 105 bugs taken systematically from 5.1 millions of lines of code with 10,000 test cases ...
  - Our genetic algorithm can repair 55 of them
  - For only $7.32 each!
  - Typical human cost: $25
- Why should you care?
  - **Ethan Fast**, now at Stanford Grad School
  - **Briana Satchell**, now at UMass Amherst Grad School

Homework

- PS 5!
  - Due Friday 21 October
  - It is longer than PS4.
  - If you wait, you will probably not have enough time.
- Read Course Book 9
- Plus anything else Dave Evans assigned ...