Variables, Environments and Closures


5x-2=13
then
x = 3
But professor, you said yesterday that x was equal to 2!

Overview

We will

- Touch on the notions of variable extent and scope
- Introduce the notions of lexical scope and dynamic scope for variables
- Provide a simple model for variable environments in Scheme
- Show examples of closures in Scheme

Variables, free and bound

- In this function, to what does the variable *GOOGOL* refer?

```
(define (big-number? x)
    ;; returns true if x is a really big number
    (> x GOOGOL))
```

- The **scope** of the variable X is just the body of the function for which it's a parameter.

Here, GOOGOL is a global variable

```
> (define GOOGOL (expt 10 100))
> GOOGOL
100000000000000000000000000000000000000
000000000000000000000000000000000000000
00000000000000000000000
> (define (big-number? x) (> x GOOGOL))
> (big-number? (add1 (expt 10 100)))
#t
```

Which X is accessed at the end?

```
> (define GOOGOL (expt 10 100))
> GOOGOL
10000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000
0000000000000
> (define x -1)
> (define (big-number? x) (> x GOOGOL))
> (big-number? (add1 (expt 10 100)))
#t
```

Variables, free and bound

- In the body of this function, we say that the variable (or symbol) X is **bound** and GOOGOL is **free**

```
(define (big-number? x)
  ; returns true if X is a really big number
  (> X GOOGOL))
```

- If it has a value, it has to be bound somewhere else

The let form creates local variables

```
> (let [ (pi 3.1415)
         (e 2.7168) ]
     (big-number? (expt pi e)))
#f
```

Note: square brackets are like parens, but only match other square brackets. They can to help you cope with paren fatigue.

- The general form is (let <varlist> . <body>)
- It creates a local environment, binding the variables to their initial values, and evaluates the expressions in <body>

Let creates a block of expressions

```
(if (> a b)
    (let ( )
        (printf "a is bigger than b.~n")
        (printf "b is smaller than a.~n")
        #t)
    #f)
```

Let is just syntactic sugar for lambda

```
(let [(pi 3.1415) (e 2.7168)]
   (big-number? (expt pi e)))

((lambda (pi e) (big-number? (expt pi e)))
  3.1415
  2.7168)
```

and this is how we did it back before ~1973

Let is just syntactic sugar for lambda

What happens here:

```
(define x 2)
(let [ (x 10) (xx (* x 2)) ]
   (printf "x is ~s and xx is ~s.~n" x xx))
```

x is 10 and xx is 4.

Let is just syntactic sugar for lambda

What happens here:

```
(define x 2)

( (lambda (x xx) (printf "x is ~s and xx is ~s.~n" x xx))
  10
  (* 2 x))
```

x is 10 and xx is 4.

Let is just syntactic sugar for lambda

What happens here:

```
(define x 2)

(define (f000034 x xx)
  (printf "x is ~s and xx is ~s.~n" x xx))
(f000034 10 (* 2 x))
```

x is 10 and xx is 4.

let and let*

- The let special form evaluates all initial value expressions, and then creates a new environment with local variables bound to them, "in parallel"
- The let* form does is sequentially
- let* expands to a series of nested lets

```
(let* [(x 100)(xx (* 2 x))] (foo x xx) )
(let [(x 100)]
    (let [(xx (* 2 x))]
      (foo x xx) ) )
```

What happens here?

```
> (define X 10)
> (let [(X (* X X))]
      (printf "X is ~s.~n" X)
      (set! X 1000)
      (printf "X is ~s.~n" X)
      -1 )
???
> X
???
```

What happens here?

```
> (define X 10)
➢ (let [(X (* X X))]
      (printf “X is ~s\n” X)
      (set! X 1000)
      (printf “X is ~s\n” X)
      -1 )
X is 100
X is 1000
-1
> X
10
```

What happens here?

```
> (define GOOGOL (expt 10 100))
> (define (big-number? x) (> x GOOGOL))
> (let [(GOOGOL (expt 10 101))]
    (big-number? (add1 (expt 10 100))))
???
```

What happens here?

```
> (define GOOGOL (expt 10 100))
> (define (big-number? x) (> x GOOGOL))
> (let [(GOOGOL (expt 10 101))]
    (big-number? (add1 (expt 10 100))))
#t
```

- The free variable GOOGOL is looked up in the environment in which the big-number? Function was defined!
- Not in the environment in which it was called

functions

- Note that a simple notion of a function can give us the machinery for
  - Creating a block of code with a sequence of expressions to be evaluated in order
  - Creating a block of code with one or more local variables
- Functional programming language is to use functions to provide other familiar constructs (e.g., objects)
- And also constructs that are unfamiliar

Dynamic vs. Static Scoping

- Programming languages either use dynamic or static (aka lexical) scoping
- In a statically scoped language, free variables in functions are looked up in the environment in which the function is defined
- In a dynamically scoped language, free variables are looked up in the environment in which the function is called

History

- Lisp started out as a dynamically scoped language and moved to static scoping with Common Lisp in ~1980
- Today, fewer languages use only dynnamic scoping, Logo and Emacs Lisp among them
- Perl and Common Lisp let you define some variables as dynamically scoped

Dynamic scoping

Here's a model for dynamic binding:

- Variables have a global stack of bindings
- Creating a new variable X in a block pushes a binding onto the global X stack
- Exiting the block pops X's binding stack
- Accessing X always produces the top binding

Special variables in Lisp

- Common Lisp's dynamically scoped variables are called special variables
- Declare a variable special using defvar

```
> (set 'reg 5)
5
> (defun check-reg () reg)
CHECK-REG
> (check-reg)
5
> (let ((reg 6)) (check-reg))
5
```

```
> (defvar *spe* 5)
*SPEC*
> (defun check-spe () *spe*)
CHECK-SPEC
> (check-spec)
5
> (let ((*spe* 6)) (check-spe))
6
```

Advantages and disadvantages

- + Easy to implement
- + Easy to modify a function's behavior by dynamically rebinding free variables

  (let ((IO stderr)) (printf "warning…"))
- - Can unintentionally shadow a global variable
- - A compiler can never know what a free variable will refer to, making type checking impossible

Closures

- Lisp is a **lexically scoped** language
- Free variables referenced in a function those are looked up in the environment in which the function is defined

  Free variables are those a function (or block) doesn't create scope for
- A **closure** is a function that remembers the environment in which it was created
- An **environment** is just a collection of variable names and their values, plus a parent environment

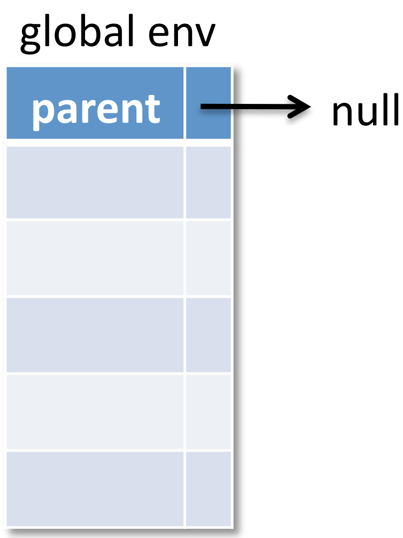
Example: make-counter

- make-counter creates an environment using let with a local variable *C* initially 0
- It defines and returns a new function, using lambda, that can access & modify *C*

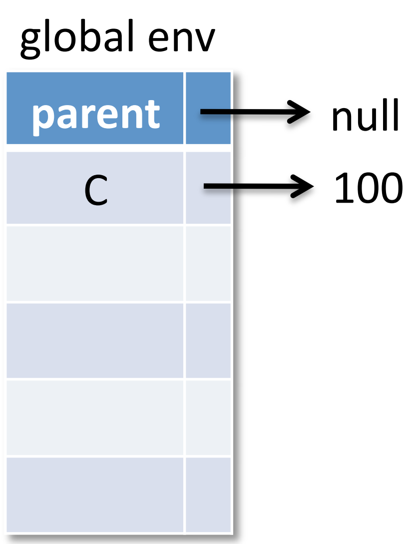
```
> (define (make-counter)
    (let ((C 0))
      (lambda ()
        (set! C (+ 1 C))
        C)))
> (define c1 (make-counter))
> (define c2 (make-counter))
```

```
> (c1)
1
> (c1)
2
> (c1)
3
> (c2)
???
```

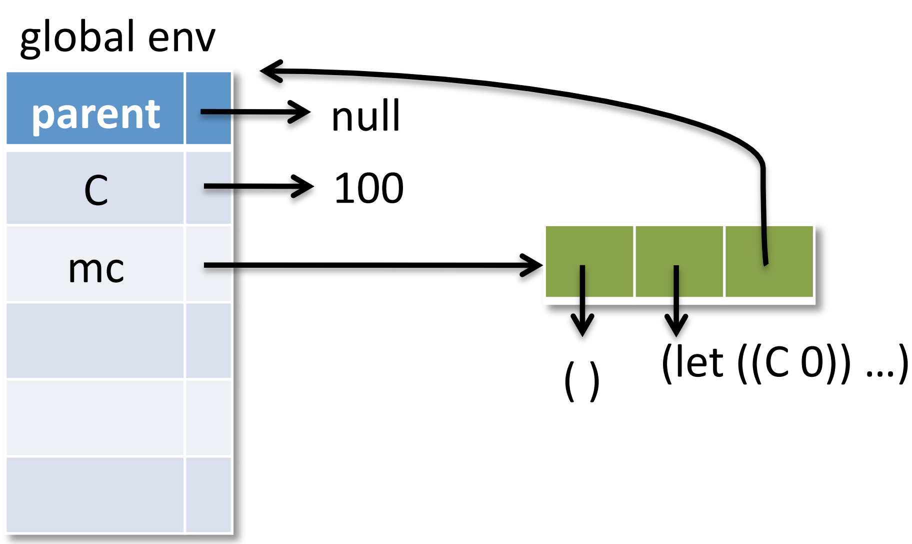
```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



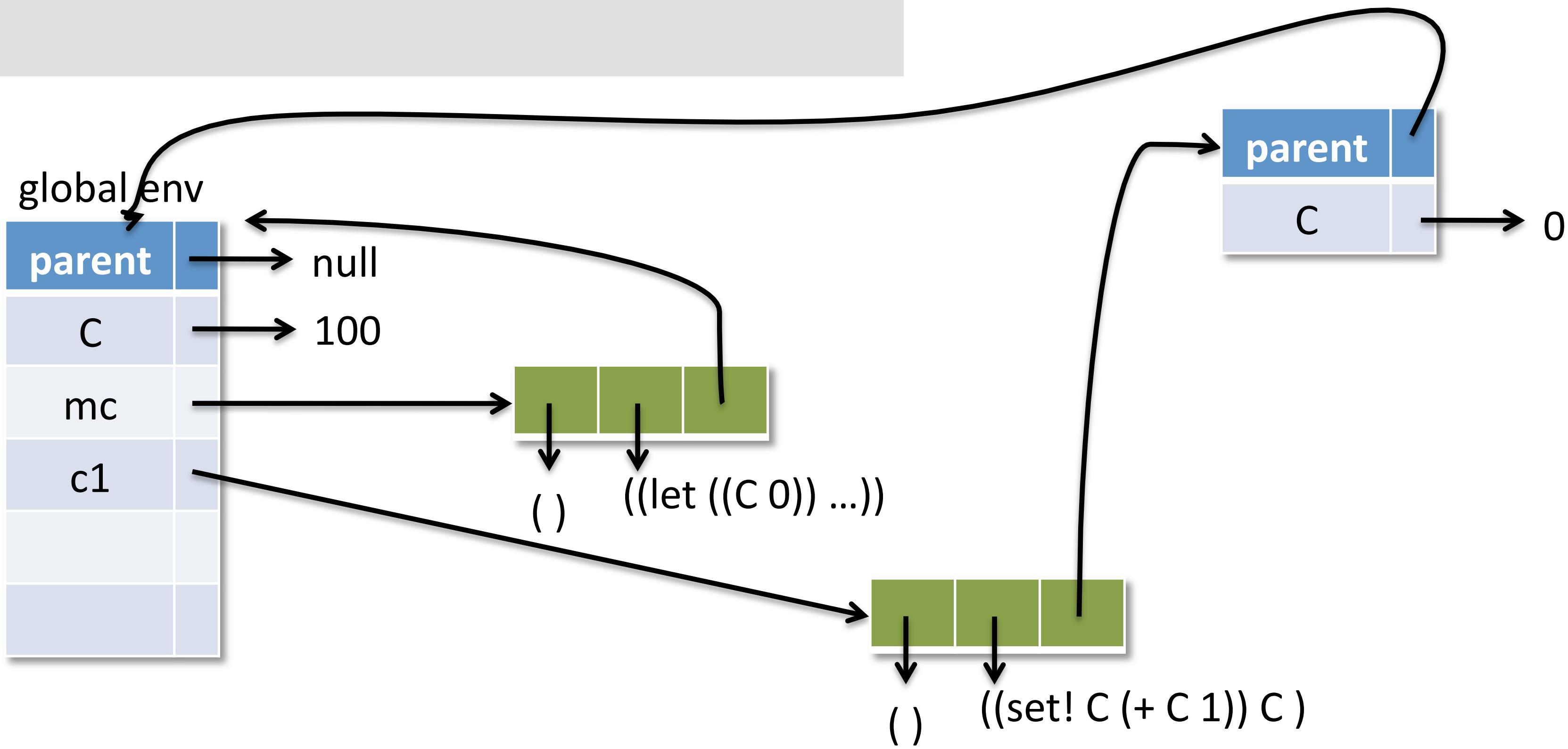
```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



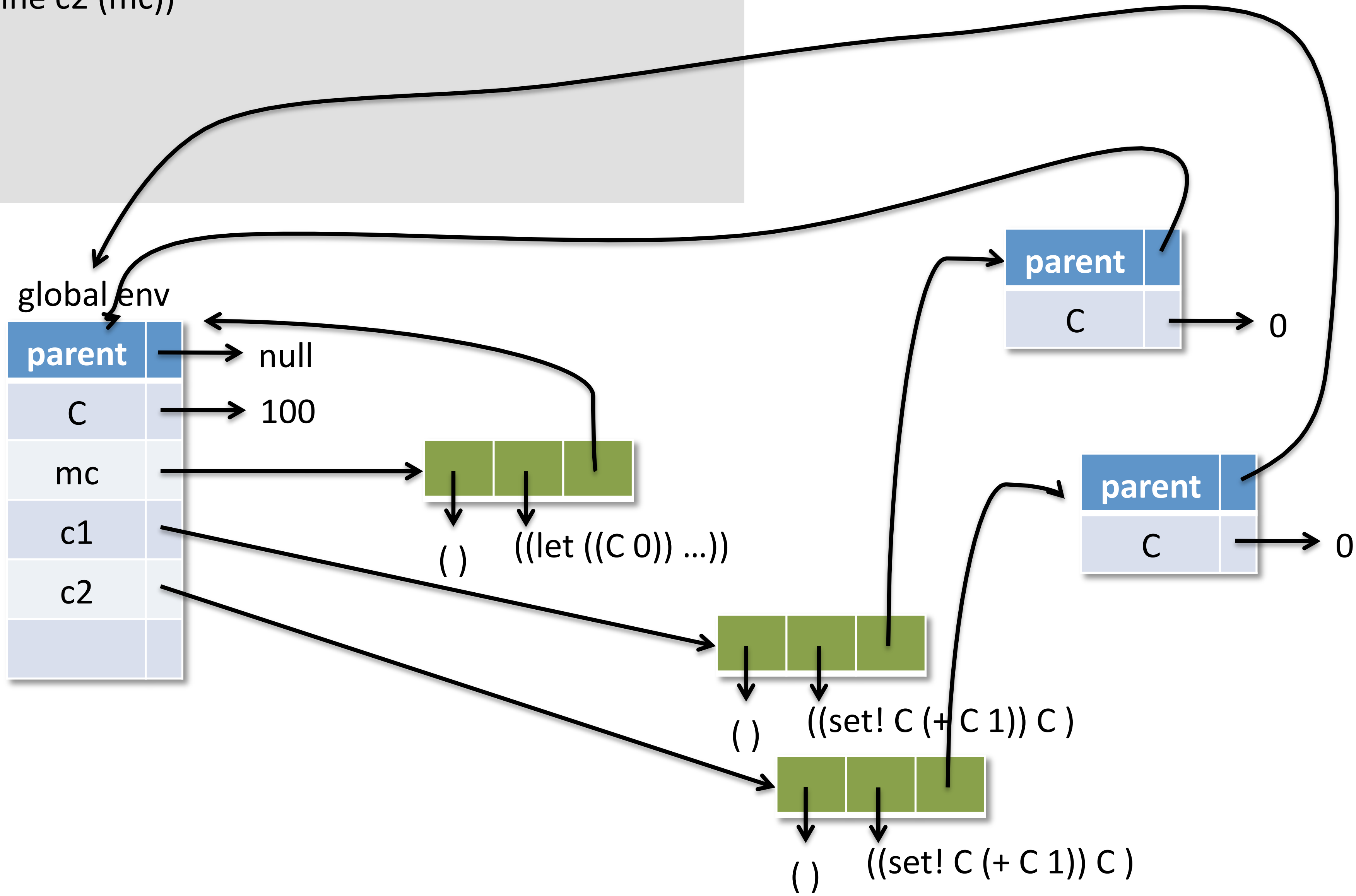
```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



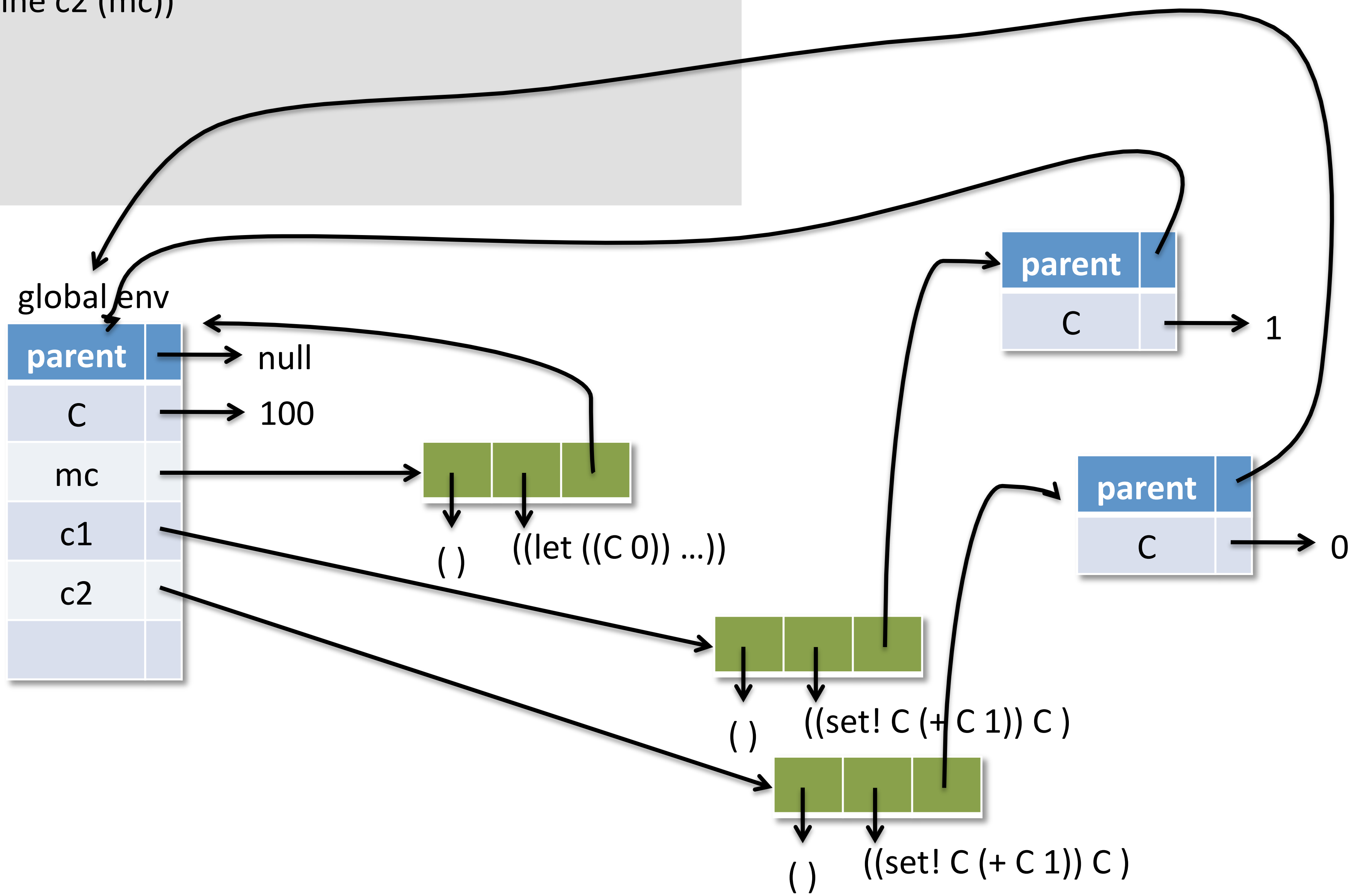
```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



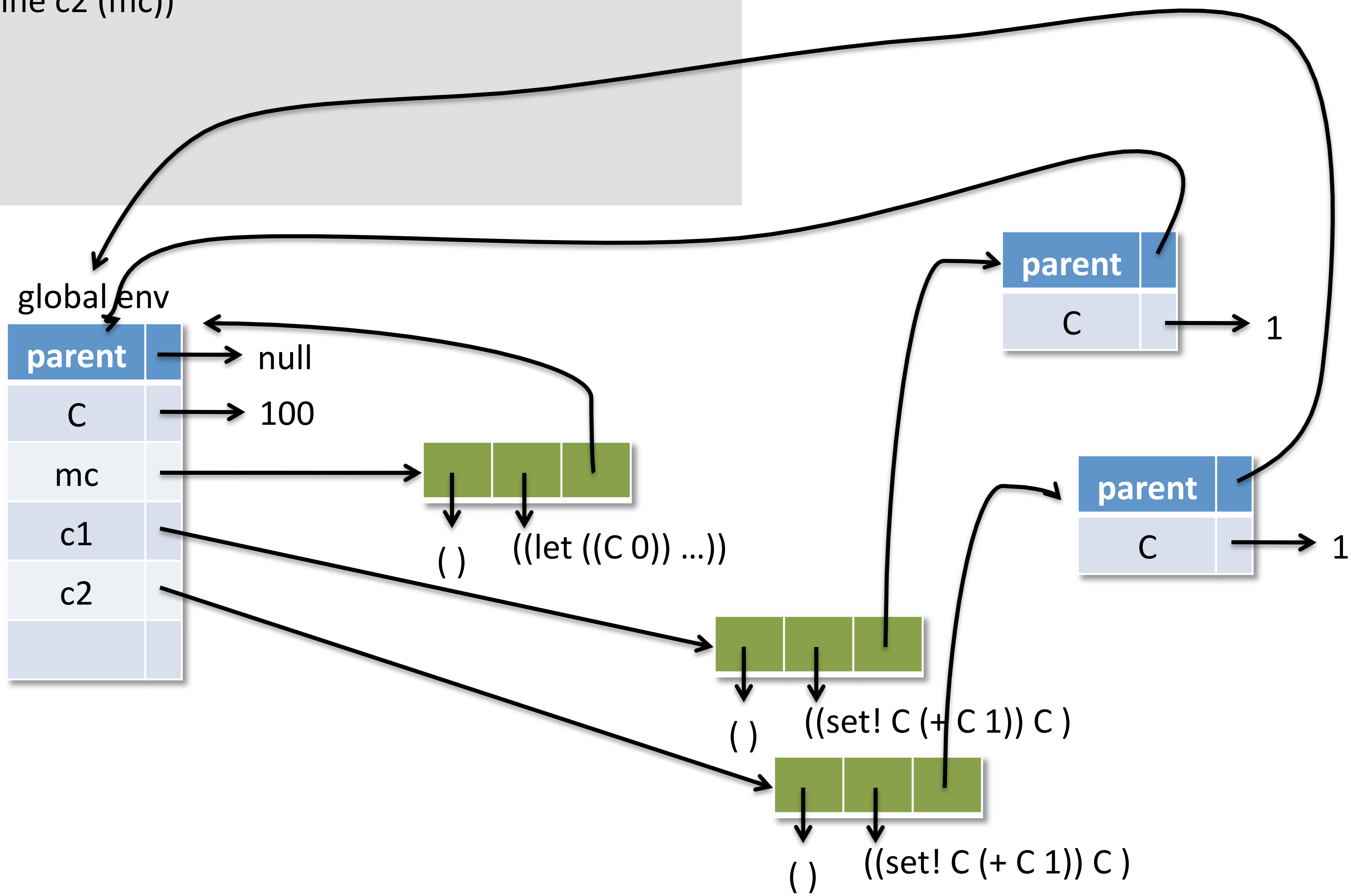
```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



```
> (define C 100)
> (define (mc) (let ((C 0)) (lambda () (set! C (+ C 1)) C)))
> (define c1 (mc))
> (define c2 (mc))
> (c1)
1
> (c2)
1
```



A fancier make-counter

Write a fancier make-counter function that takes an optional argument that specifies the increment

```
> (define by1 (make-counter))
> (define by2 (make-counter 2))
> (define decrement (make-counter -1))
> (by2)
2
(by2)
4
```

Optional arguments in Scheme

```
> (define (f (x 10) (y 20))
      (printf "x=~a and y=~a\n" x y))
> (f)
x=10 and y=20
> (f -1)
x=-1 and y=20
> (f -1 -2)
x=-1 and y=-2
```

Fancier make-counter

```
(define (make-counter (inc 1))
 (let ((C 0))
    (lambda ( ) (set! C (+ C inc)))))
```

Keyword arguments in Scheme

- Scheme, like Lisp, also has a way to define functions that take *keyword arguments*
  - (make-counter)
  - (make-counter :initial 100)
  - (make-counter :increment -1)
  - (make-counter :initial 10 :increment -2)
- Different Scheme dialects have introduced different ways to mix positional arguments, optional arguments, default values, keyword argument, etc.

Closure tricks

We can write several functions that are closed in the same environment, which can then provide a private communication channel

```
(define foo #f)
(define bar #f)
(let ((secret-msg "none"))
  (set! foo
    (lambda (msg)
      (set! secret-msg msg)))
  (set! bar
    (lambda () secret-msg)))
(display (bar)) ; prints "none"
(newline)
(foo ”attack at dawn")
(display (bar)) ; prints ”attack at
dawn"
```

Summary

- Scheme, like most modern languages, is lexically scoped
- Common Lisp is by default, but still allows some variables to be declared to be dynamically scoped
- A few languages still use dynamic scoping
- Lexical scoping supports functional programming & powerful mechanisms (e.g., closures)
- More complex to implement, though