## Assignment in Scheme

So far, we have one form of assignment: **vector-set!**

```
(let ([v (vector 1 2 3)])
  (begin
    (vector-set! v 1 72)
    v))
→→
#(1 72 3)
```

## Assignment in Scheme

Scheme actually allows variables to be modified:

```
(let ([x 2])
  (begin
    (set! x 73)
    x))
→→
73
```

- *Don't write Scheme code like that*, except for HW6
- But many languages have assignment, and need it

## Assignment in the Book Language

- Add a **set** expression form:

<expr> ::= **set** <id> = <expr>

## Evaluating with Assignment

Can't write this, since we don't have **begin** in our language

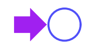
```
let x = 10
    y = 12
  in (begin set x = +(x,1)
       x)
```

## Evaluating with Assignment

Instead, use a binding for a dummy variable **d** to sequence expressions; initial environment is empty

**let x** = 10
**y** = 12
**in let d** = **set x** = +(**x**,1)
**in x**

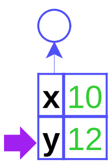
## Evaluating with Assignment



Eval RHS (right-hand side) of the let expression

**let x** = 10
**y** = 12
**in let d** = **set x** = +(**x**,1)
**in x**

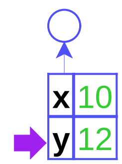
## Evaluating with Assignment




Extend the current environment with **x** and **y**, and eval body

**let x** = 10
**y** = 12
**in let d** = **set x** = +(**x**,1)
**in x**

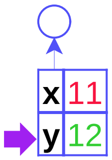
## Evaluating with Assignment




Eval RHS of the let expression

**let x** = 10
**y** = 12
**in let d** = **set x** = +(**x**,1)
**in x**

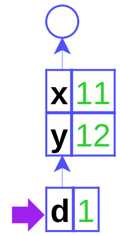
## Evaluating with Assignment




It modifies the **x** in the current lexical scope; we define **set** to always return 1

**let x** = 10
  **y** = 12
 **in let d** = **set x** = +(**x**,1)
   **in x**

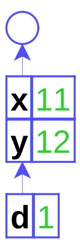
## Evaluating with Assignment




Bind **d** to the result 1; to eval the body, **x**, we look it up in the environment as usual, and find 11

**let x** = 10
  **y** = 12
 **in let d** = **set x** = +(**x**,1)
   **in x**

## Evaluating with Assignment




➤ Variables now correspond to boxes in the environment, not fixed values

**let x** = 10
  **y** = 12
 **in let d** = **set x** = +(**x**,1)
   **in x**

## Expressed and Denoted Values

| | | |
|---|---|---|
| <expval> | ::= | <num> |
| | ::= | <proc> |
| <denval> | ::= | <reference> |

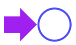
- New datatype:

```
(define-datatype reference reference?
  (a-ref (pos integer?)
         (vec vector?)))
```

- New function:

```
apply-env-ref : env sym -> ref
```

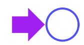
## Assignment and Closures



An example with **proc**; again, we start with the empty environment

```
let x = 10
    y = 12
  in let f = proc(z)+(z,x)
      in let d = set x = +(x,1)
          in (f 0)
```

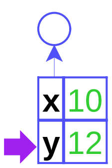
## Assignment and Closures



Eval RHS of the let expression

```
let x = 10
    y = 12
  in let f = proc(z)+(z,x)
      in let d = set x = +(x,1)
          in (f 0)
```

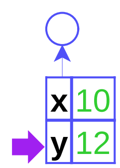
## Assignment and Closures




Extend the current environment with **x** and **y**, and eval body

```
let x = 10
    y = 12
  in let f = proc(z)+(z,x)
      in let d = set x = +(x,1)
          in (f 0)
```

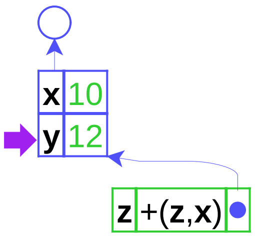
## Assignment and Closures




Eval RHS of the let expression...

```
let x = 10
    y = 12
  in let f = proc(z)+(z,x)
      in let d = set x = +(x,1)
          in (f 0)
```

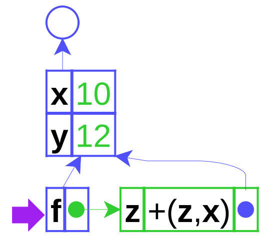
## Assignment and Closures




... which creates a closure, pointing to the current environment

**let x** = 10  
  **y** = 12  
 **in let f** = **proc**(**z**)+(**z**,**x**)  
   **in let d** = **set x** = +(**x**,1)  
     **in** (**f** 0)

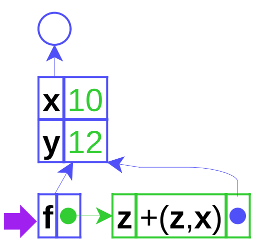
## Assignment and Closures




To finish the **let**, the environment is extended with **f** bound to the closure; then evaluate the body

**let x** = 10  
  **y** = 12  
 **in let f** = **proc**(**z**)+(**z**,**x**)  
   **in let d** = **set x** = +(**x**,1)  
     **in** (**f** 0)

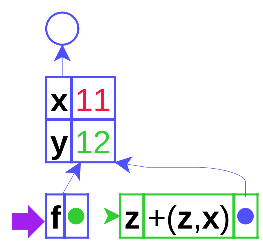
## Assignment and Closures




Eval RHS of the let expression...

**let x** = 10  
  **y** = 12  
 **in let f** = **proc**(**z**)+(**z**,**x**)  
   **in let d** = **set x** = +(**x**,1)  
     **in** (**f** 0)

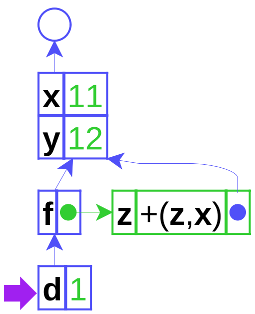
## Assignment and Closures




... which changes the value of **x**, then produces 1

**let x** = 10  
  **y** = 12  
 **in let f** = **proc**(**z**)+(**z**,**x**)  
   **in let d** = **set x** = +(**x**,1)  
     **in** (**f** 0)

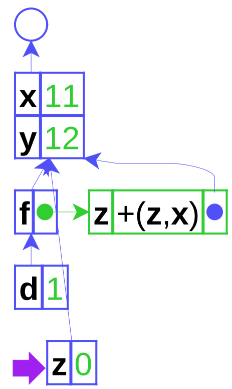
## Assignment and Closures




To eval the body, (**f** 0), we look up **f** in the environment to find a closure, and evaluate 0 to 0

**let x** = 10
  **y** = 12
 **in let f** = **proc**(**z**)+(**z**,**x**)
   **in let d** = **set x** = +(**x**,1)
     **in** (**f** 0)

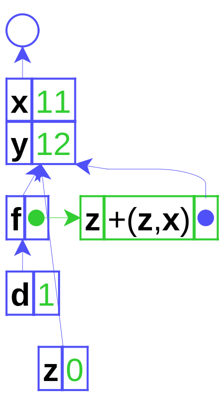
## Assignment and Closures




Extend the *closure's* environment with 0 for **z**, and evaluate the closure's body in that environment; the result will be 11

**let x** = 10
  **y** = 12
 **in let f** = **proc**(**z**)+(**z**,**x**)
   **in let d** = **set x** = +(**x**,1)
     **in** (**f** 0)

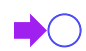
## Assignment and Closures




- By capturing environments, closures capture variables that may change

**let x** = 10
  **y** = 12
 **in let f** = **proc**(**z**)+(**z**,**x**)
   **in let d** = **set x** = +(**x**,1)
     **in** (**f** 0)

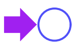
## Assignment and Arguments



Another example with **proc**, but with the **let** inside the **proc**

**let f** = **proc**(**z**)
      **let x** = 10
       **in let d** = **set x** = +(**x**,**z**)
         **in x**
 **in** +((**f** 1), (**f** 9))

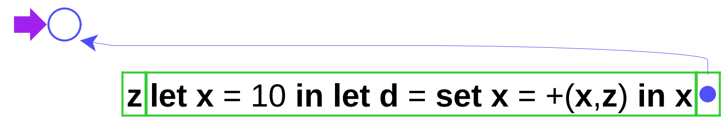
## Assignment and Arguments



Eval RHS of the let expression...

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

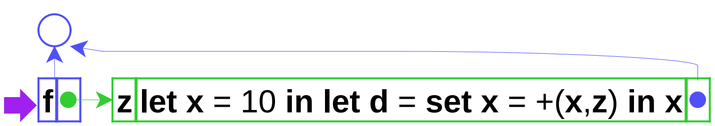
## Assignment and Arguments




... which creates a closure, pointing to the current environment

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

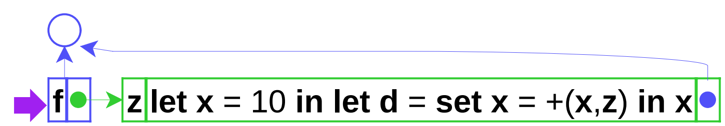
## Assignment and Arguments




Bind the closure to **f** and eval the body

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

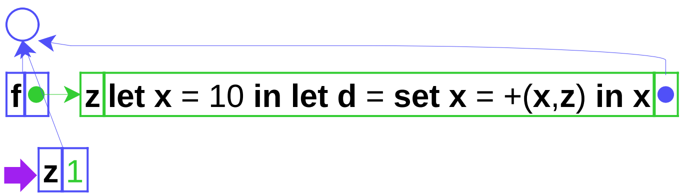
## Assignment and Arguments




Evaluate the first operand, (**f** 1)

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

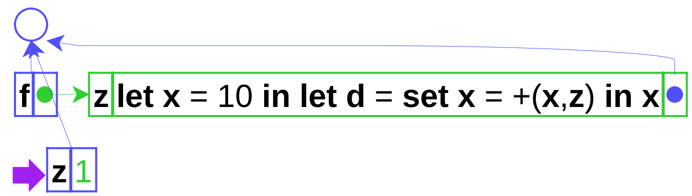
## Assignment and Arguments




Take the closure for **f**, extend its environment with a binding for **z**, and eval the closure's body

**let f** = **proc**(**z**)
  **let x** = 10
  **in let d** = **set x** = +(**x**,**z**)
  **in x**
**in** +((**f** 1), (**f** 9))

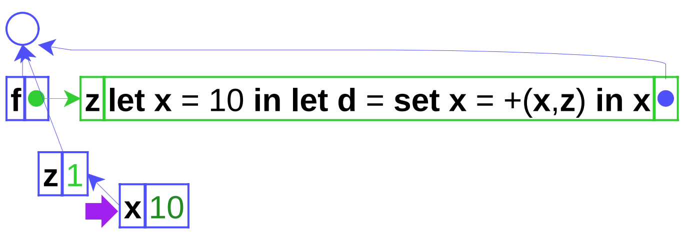
## Assignment and Arguments




Eval the RHS

**let f** = **proc**(**z**)
  **let x** = 10
  **in let d** = **set x** = +(**x**,**z**)
  **in x**
**in** +((**f** 1), (**f** 9))

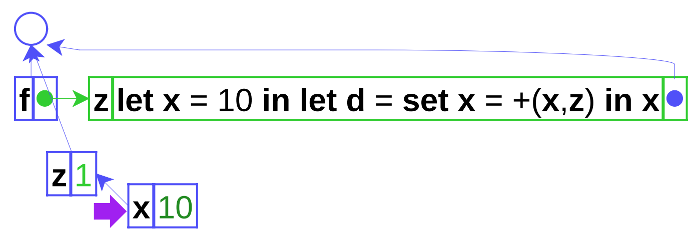
## Assignment and Arguments




Add the binding for **x** and eval the inner body

**let f** = **proc**(**z**)
  **let x** = 10
  **in let d** = **set x** = +(**x**,**z**)
  **in x**
**in** +((**f** 1), (**f** 9))

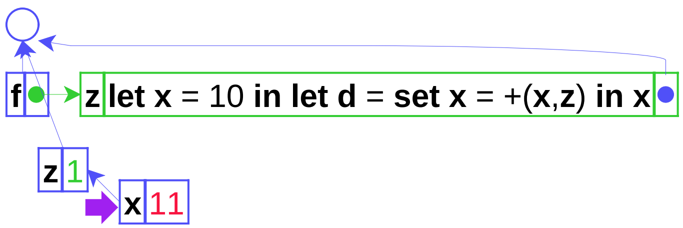
## Assignment and Arguments




Eval RHS...

**let f** = **proc**(**z**)
  **let x** = 10
  **in let d** = **set x** = +(**x**,**z**)
  **in x**
**in** +((**f** 1), (**f** 9))

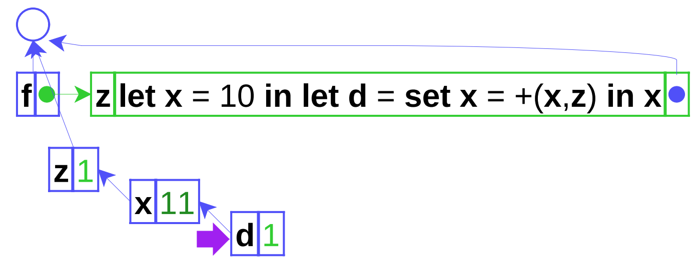
## Assignment and Arguments




... which modifies the value of **x**

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

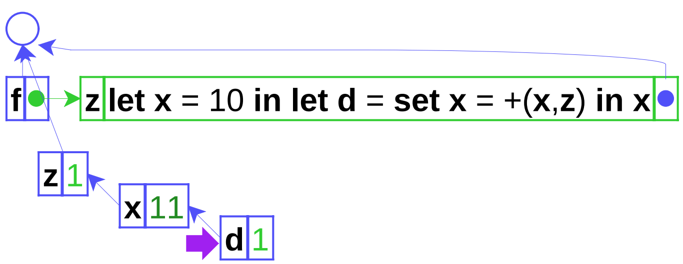
## Assignment and Arguments




Bind **d** to 1 and evaluate **x**, which produces 11

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

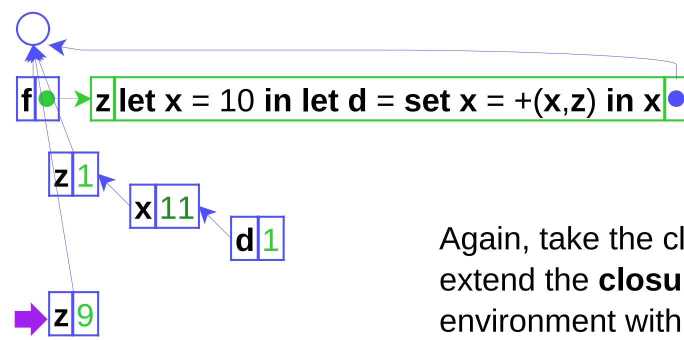
## Assignment and Arguments




First operand is 11; now evaluate the second operand, (**f** 9)

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

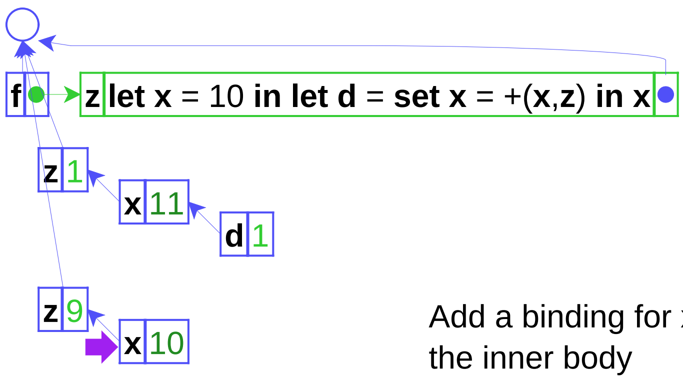
## Assignment and Arguments




Again, take the closure for **f**, extend the **closure's** environment with a binding for **z**, and eval the closure's body

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

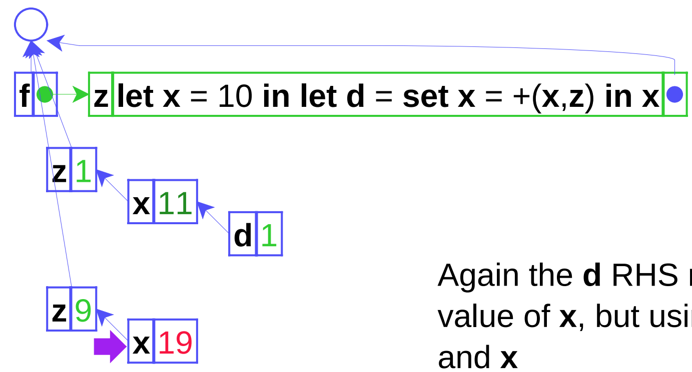
## Assignment and Arguments




Add a binding for **x**, then eval the inner body

```
let f = proc(z)
         let x = 10
          in let d = set x = +(x,z)
             in x
 in +((f 1), (f 9))
```

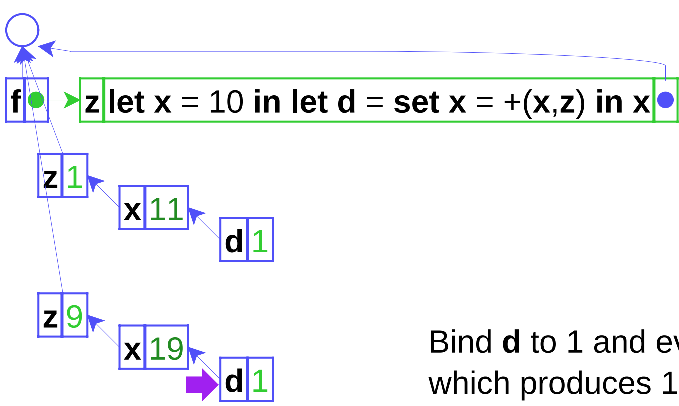
## Assignment and Arguments




Again the **d** RHS modifies the value of **x**, but using the new **z** and **x**

```
let f = proc(z)
         let x = 10
          in let d = set x = +(x,z)
             in x
 in +((f 1), (f 9))
```

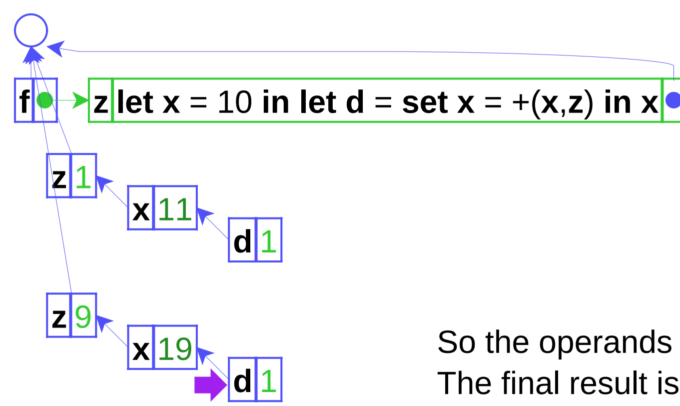
## Assignment and Arguments




Bind **d** to 1 and evaluate **x**, which produces 19

```
let f = proc(z)
         let x = 10
          in let d = set x = +(x,z)
             in x
 in +((f 1), (f 9))
```

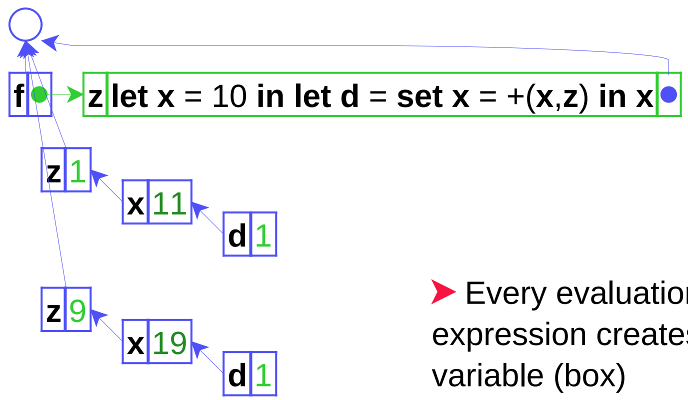
## Assignment and Arguments




So the operands are 11 and 19; The final result is 30

```
let f = proc(z)
         let x = 10
          in let d = set x = +(x,z)
             in x
 in +((f 1), (f 9))
```

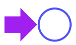
## Assignment and Arguments




➤ Every evaluation of a binding expression creates a new variable (box)

```
let f = proc(z)
          let x = 10
           in let d = set x = +(x,z)
              in x
 in +((f 1), (f 9))
```

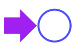
## Assignment and Locals within Procedures



An example with a procedure in a procedure

```
let mk = proc(x) proc(z)
                  let d = set x = +(x,z) in x
 in let f = (mk 10)
    in let g = (mk 12)   in ...
```

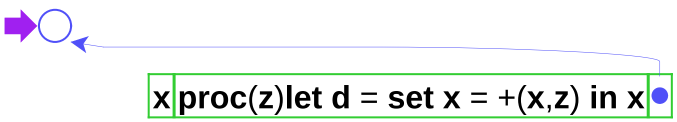
## Assignment and Locals within Procedures



Eval RHS of the let expression...

```
let mk = proc(x) proc(z)
                  let d = set x = +(x,z) in x
 in let f = (mk 10)
    in let g = (mk 12)   in ...
```

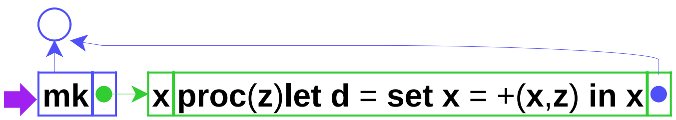
## Assignment and Locals within Procedures




... which creates a closure, pointing to the current environment

```
let mk = proc(x) proc(z)
                  let d = set x = +(x,z) in x
 in let f = (mk 10)
    in let g = (mk 12)   in ...
```

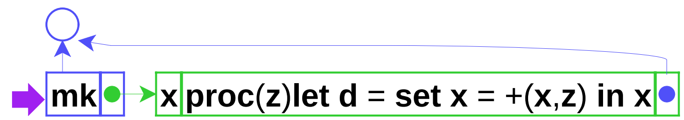
## Assignment and Locals within Procedures




To finish the **let**, the environment is extended with **mk** bound to the closure, then evaluate the body

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

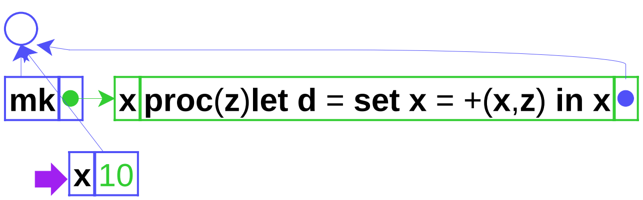
## Assignment and Locals within Procedures




Eval RHS, a function call; look up **mk**...

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

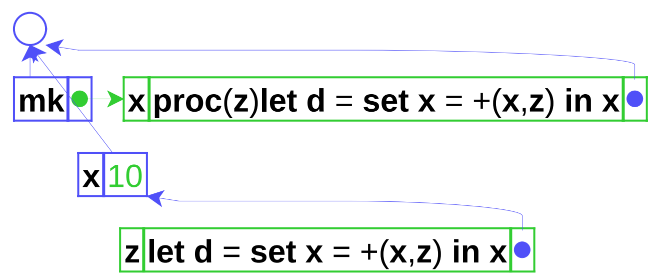
## Assignment and Locals within Procedures




It's a closure, so extend the closure's environment with 10, and eval the closure's body

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

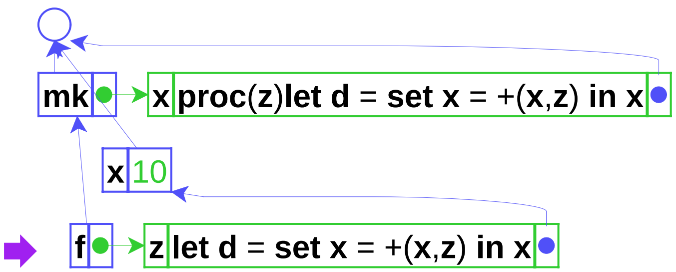
## Assignment and Locals within Procedures




Note that the variable **x** is in the closure's environment

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

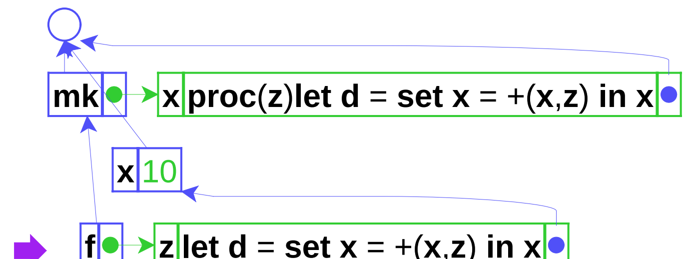
## Assignment and Locals within Procedures




Bind **f** to the closure, and evaluate the body

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

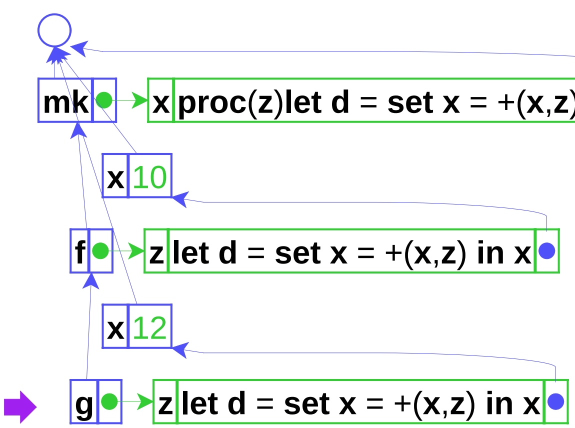
## Assignment and Locals within Procedures




Eval RHS of the let expression, another call to **mk**; same as before...

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

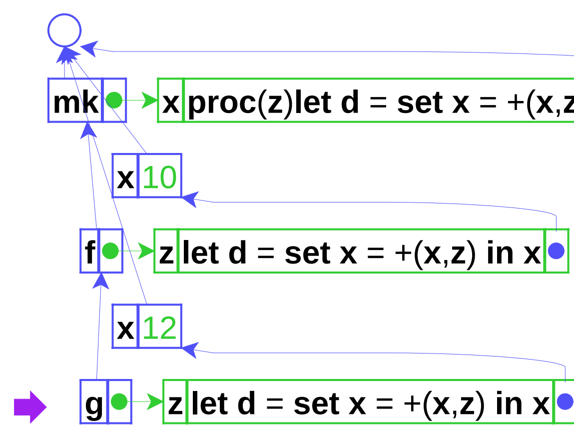
## Assignment and Locals within Procedures




Extend **mk**'s env with a new **x** and get a closure, this time bound to **g**

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

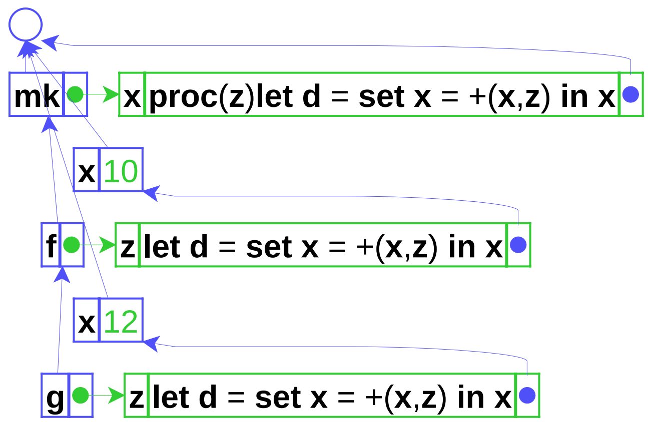
## Assignment and Locals within Procedures




At this point, **f** and **g** have private versions of **x**

**let mk** = **proc**(x) **proc**(z)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

## Assignment and Locals within Procedures




- Closures can capture generated variables, effectively getting private state

**let mk** = **proc**(**x**) **proc**(**z**)
**let d** = **set x** = +(**x**,**z**) **in x**
**in let f** = (**mk** 10)
**in let g** = (**mk** 12) **in ...**

## Assignment Summary

- Variables now denote references (a.k.a. locations), not values
- Lexical scope still works