Reminder

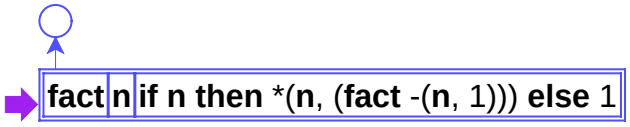
Mid-Term 1 is Tuesday next week

(No homework will be assigned this week)

Recap: Recursive Environments

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

Recap: Recursive Environments



double box means a recursively extended environment

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
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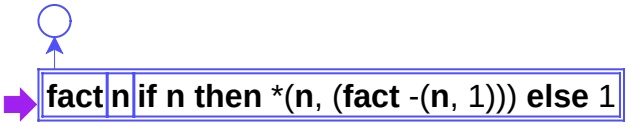
Recap: Recursive Environments



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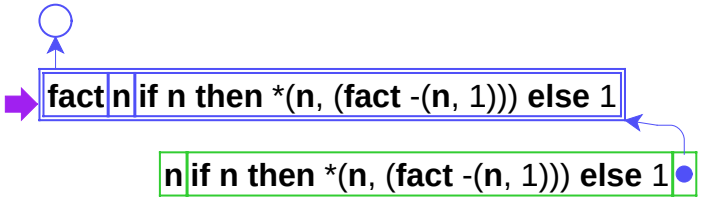

every lookup of **fact**
generates a closure

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
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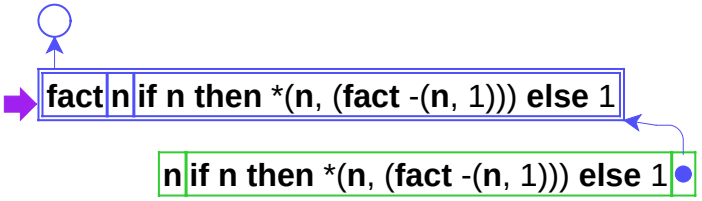
Recap: Recursive Environments



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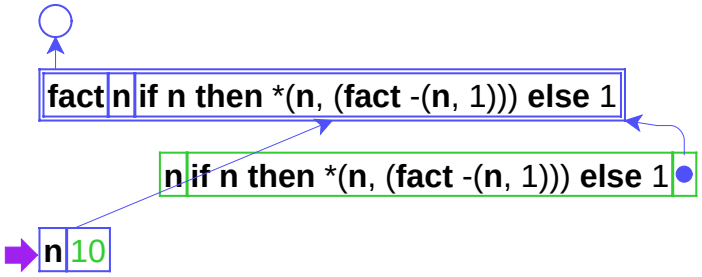

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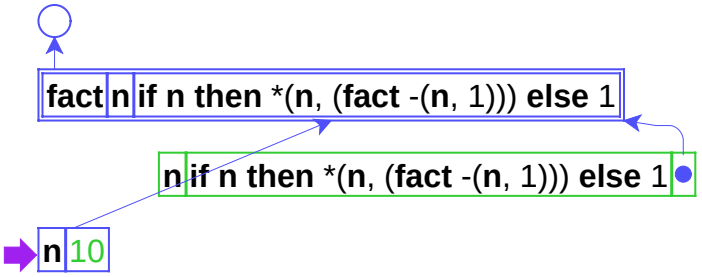

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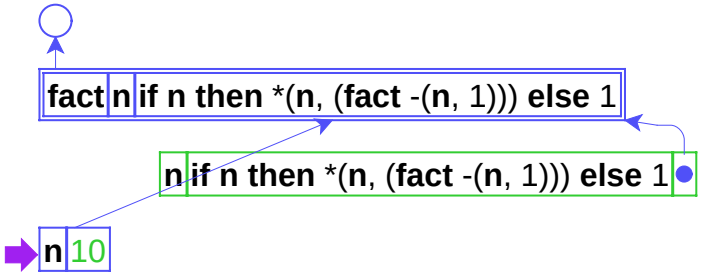

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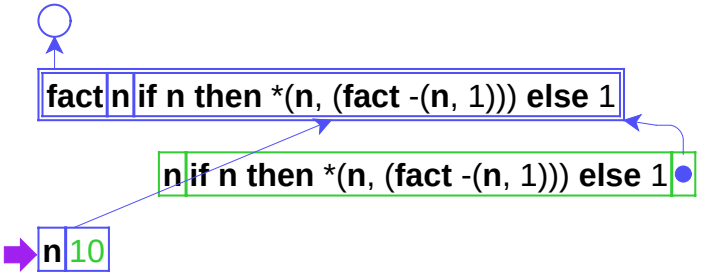

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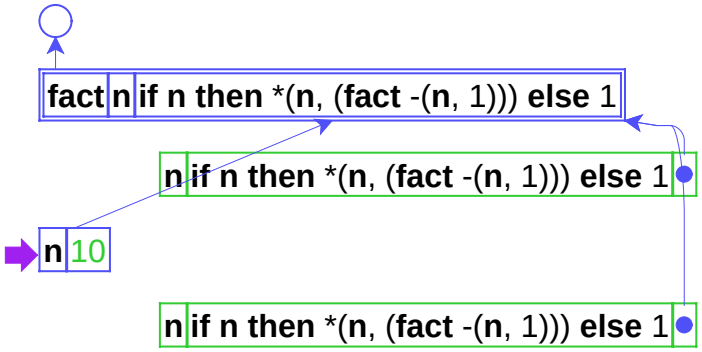

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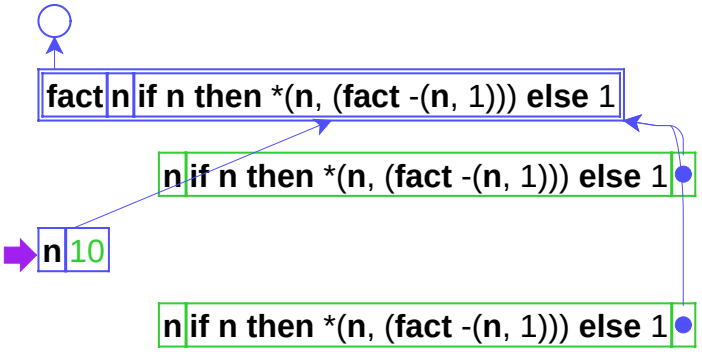

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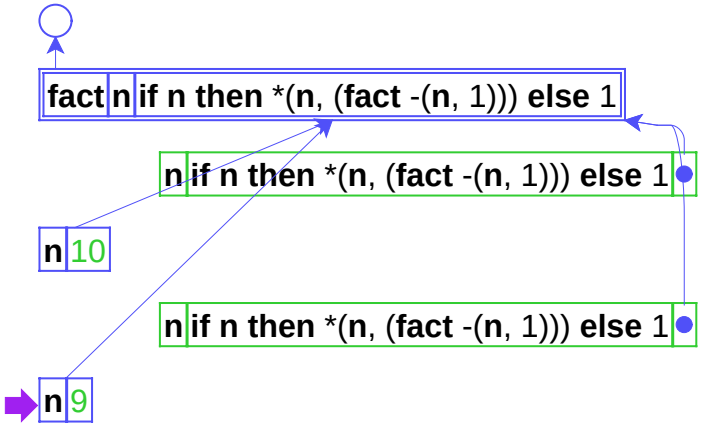


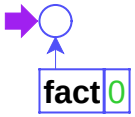
letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

Another Approach to Recursive Closures

alternate approach...

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

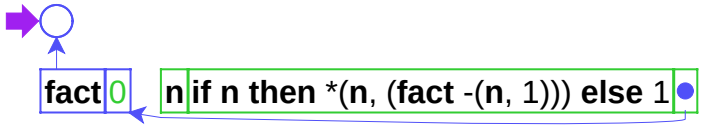
Another Approach to Recursive Closures



create an environment with a dummy value...

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

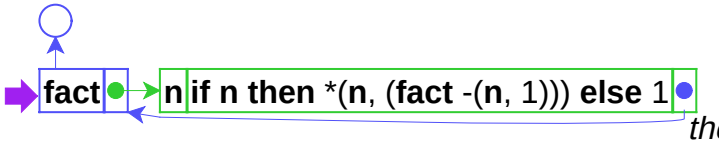
Another Approach to Recursive Closures



create the closure using the environment...

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

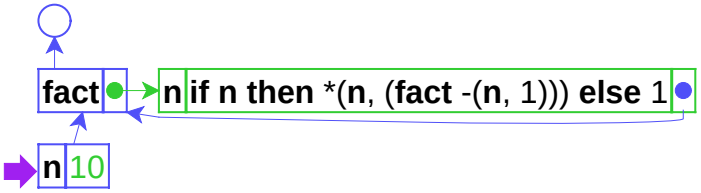
Another Approach to Recursive Closures



then
modify
the environment
to fix it up

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

Another Approach to Recursive Closures



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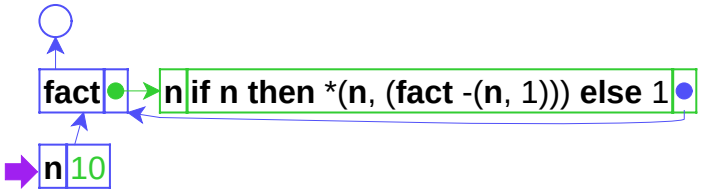
Another Approach to Recursive Closures



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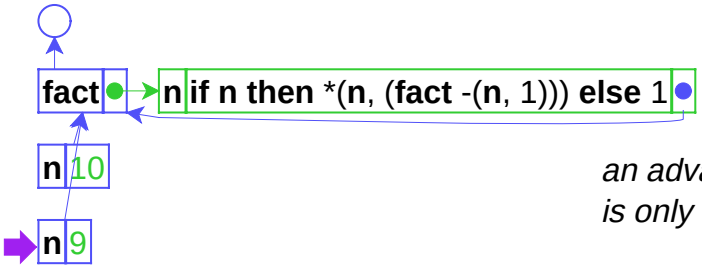
Another Approach to Recursive Closures



an advantage: closure
is only created once

letrec fact = **proc**(**n**) **if n then** *(**n**, (**fact** -(**n**, 1))) **else** 1
in (**fact** 10)

Modifying Environments

- Nothing in Scheme so far supports *modifying* a value
- So we need evaluation rules to support ***vectors*** and ***vector update***

Evaluation of Vector Expressions

- Unlike **cons**, **vector** does not create a value
- Instead, it's treated like local functions used to be

...
(**let** ([**v** (**vector** 1 2 3)]) (**vector-ref v** 0))
→
... (**define vec**$_{1743}$ (**vector** 1 2 3))
(**let** ([**v vec**$_{1743}$]) (**vector-ref v** 0))
→
... (**define vec**$_{1743}$ (**vector** 1 2 3))
(**vector-ref vec**$_{1743}$ 0)
→
... (**define vec**$_{1743}$ (**vector** 1 2 3))
1

Evaluation of Vector Expressions

- The reason for this definition of **vector** is to enable **vector-set!**

...
(**let** ([**v** (**vector** 1 2 3)]) (**begin** (**vector-set! v** 0 5) (**vector-ref v** 0)))
→
... (**define vec**$_{1743}$ (**vector** 1 2 3))
(**let** ([**v vec**$_{1743}$]) (**begin** (**vector-set! v** 0 5) (**vector-ref v** 0)))
→
... (**define vec**$_{1743}$ (**vector** 1 2 3))
(**begin** (**vector-set! vec**$_{1743}$ 0 5) (**vector-ref vec**$_{1743}$ 0))
→
... (**define vec**$_{1743}$ (**vector** 5 2 3))
(**vector-ref vec**$_{1743}$ 0)
→
... (**define vec**$_{1743}$ (**vector** 5 2 3))
5

Begin Expressions

- **begin** evaluates a sequence of expressions, in order
- **lambda** and **let** always supply an implicit **begin**

(**let** (**...**) <expr>$_1$ **...** <expr>$_n$)
= (**let** (**...**) (**begin** <expr>$_1$ <expr>$_n$))

(**lambda** (**...**) <expr>$_1$ **...** <expr>$_n$)
= (**lambda** (**...**) (**begin** <expr>$_1$ <expr>$_n$))

Changing Recursive Environment Extension

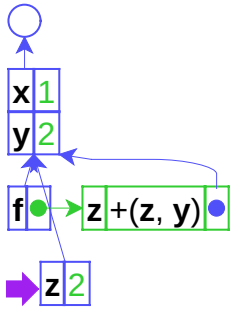
Now we can change **`extend-env-recursively`** to use **vector-set!**

Go back to just two datatype variants

```
(define-datatype environment environment?
  (empty-env-record)
  (extended-env-record
    (syms (list-of symbol?))
    (vals vector?)
    (env environment?))
```

(implement in DrScheme)

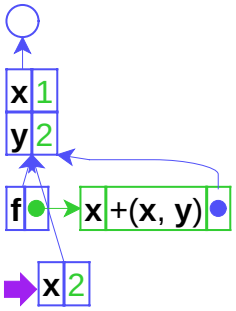
Back to Lexical Scope



What if we change **z** to **x** ?

let x = 1 **y** = 2
in let f = **proc** (**z**) +(**z**, **y**)
in (**f y**)

Back to Lexical Scope

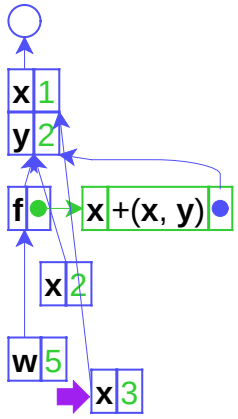


Shape of the environment and location of the argument is unchanged

- argument is always first in first frame
- **y** is always second in second frame

let x = 1 **y** = 2
in let f = **proc** (**x**) +(**x**, **y**)
in (**f y**)

Back to Lexical Scope



Still true if **f** is called from a more complex environment

let x = 1 **y** = 2
in let f = **proc** (**x**) +(**x**, **y**)
in +((**f y**), **let w** = 5 **in** (**f** 3))

Compilation

So why waste time searching the environment on every variable access?

A compiler can determine the ***lexical offset*** for each variable statically

Terminology:

- A ***compiler*** translates a program from language *X* to language *Y*
- An ***interpreter*** executes a program in language *X*

Compilation of Variable Accesses

- We'll write a compiler that transforms

```
let x = 1  y = 2
 in let f = proc (x) +(x, y)
  in (f x)
```

to

```
let _ = 1  _ = 2
 in let _ = proc (_) +(<0,0>, <1,1>)
  in (<0,0> <1,0>)
```

- We'll also need an interpreter for the new language