CSE341: Programming Languages

Section 6
What does mutation mean?
When do function bodies run?

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Agenda

- Let Expressions
- Mutation: Set!
- Delayed Evaluations: Thunks

Let

A let expression can bind any number of local variables

- Notice where all the parentheses are

The expressions are all evaluated in the environment from **before the let-expression**

- Except the body can use all the local variables of course
- This is **not** how ML let-expressions work
- Convenient for things like `(let ([x y][y x]) …)`

```
(define (silly-double x)
  (let ([x (+ x 3)]
        [y (+ x 2)])
    (+ x y -5)))
```

*Let**

Syntactically, a let* expression is a let-expression with 1 more character

The expressions are evaluated in the environment produced from the **previous bindings**

- Can repeat bindings (later ones shadow)
- This **is** how ML let-expressions work

```
(define (silly-double x)
  (let* ([x (+ x 3)]
         [y (+ x 2)])
    (+ x y -8)))
```

Letrec

Syntactically, a letrec expression is also the same

The expressions are evaluated in the environment that includes **all the bindings**

```
(define (silly-triple x)
  (letrec ([y (+ x 2)]
           [f (lambda(z) (+ z y w x))]
           [w (+ x 7)])
     (f -9)))
```

– Needed for mutual recursion
– But expressions are still *evaluated in order*: accessing an uninitialized binding raises an error
  • Remember function bodies not evaluated until called

More letrec

- Letrec is ideal for recursion (including mutual recursion)

```
(define (silly-mod2 x)
  (letrec
   ([even? (λ(x)(if (zero? x) #t (odd? (- x 1))))]
    [odd?  (λ(x)(if (zero? x) #f (even? (- x 1))))])
     (if (even? x) 0 1)))
```

- Do not use later bindings except inside functions
  - This example will raise an error when called

```
(define (bad-letrec x)
  (letrec ([y z]
           [z 13])
     (if x y z)))
```

Local defines

- In certain positions, like the beginning of function bodies, you can put defines
  - For defining local variables, same semantics as **`letrec`**

```
(define (silly-mod2 x)
  (define (even? x)(if (zero? x) #t (odd? (- x 1))))
  (define (odd? x) (if (zero? x) #f (even?(- x 1))))
  (if (even? x) 0 1))
```

- Local defines is preferred Racket style, but course materials will avoid them to emphasize **`let`**, **`let*`**, **`letrec`** distinction
  - You can choose to use them on homework or not

Top-level

The bindings in a file work like local defines, i.e., **`letrec`**

- Like ML, you can *refer to* earlier bindings
- Unlike ML, you can also *refer to* later bindings
- But refer to later bindings only in function bodies
  - Because bindings are *evaluated* in order
  - Get an error if try to use a not-yet-defined binding
- Unlike ML, cannot define the same variable twice in module
  - Would make no sense: cannot have both in environment

REPL

Unfortunate detail:

- REPL works slightly differently
  - Not quite **`let*`** or **`letrec`**
  - ☹
- Best to avoid recursive function definitions or forward references in REPL
  - Actually okay unless shadowing something (you may not know about) – then weirdness ensues
  - And calling recursive functions is fine of course

Optional: Actually…

- Racket has a module system
  - Each file is implicitly a module
    - Not really "top-level"
  - A module can shadow bindings from other modules it uses
    - Including Racket standard library
  - So we could redefine **+** or any other function
    - But poor style
    - Only shadows in our module (else messes up rest of standard library)

- (Optional note: Scheme is different)

Set!

- Unlike ML, Racket really has assignment statements
  - But used *only-when-really-appropriate!*

```
(set! x e)
```

- For the **`x`** in the current environment, subsequent lookups of **`x`** get the result of evaluating expression **`e`**
  - Any code using this **`x`** will be affected
  - Like **`x = e`** in Java, C, Python, etc.

- Once you have side-effects, sequences are useful:

```
(begin e1 e2 … en)
```

Example

Example uses **`set!`** at top-level; mutating local variables is similar

```
(define b 3)
(define f (lambda (x) (* 1 (+ x b))))
(define c (+ b 4)) ; 7
(set! b 5)
(define z (f 4))   ; 9
(define w c)       ; 7
```

Not much new here:

- Environment for closure determined when function is defined, but body is evaluated when function is called
- Once an expression produces a value, it is irrelevant how the value was produced

Top-level

- Mutating top-level definitions is particularly problematic
  - What if any code could do **`set!`** on anything?
  - How could we defend against this?

- A general principle: If something you need not to change might change, make a local copy of it. Example:

```
(define b 3)
(define f
  (let ([b b])
    (lambda (x) (* 1 (+ x b)))))
```

Could use a different name for local copy but do not need to

But wait…

- Simple elegant language design:
  - Primitives like **+** and ***** are just predefined variables bound to functions
  - But maybe that means they are mutable
  - Example continued:

```
(define f
  (let ([b b]
        [+ +]
        [* *])
    (lambda (x) (* 1 (+ x b)))))
```

  - Even that won't work if **f** uses other functions that use things that might get mutated – all functions would need to copy everything mutable they used

No such madness

In Racket, *you do not have to program like this*

- Each file is a module
- *If* a module does not use `set!` on a top-level variable, then Racket makes it constant and forbids `set!` outside the module
- Primitives like `+`, `*`, and `cons` are in a module that does not mutate them

Showed you this for the *concept* of copying to defend against mutation

- Easier defense: Do not allow mutation
- Mutable top-level bindings a highly dubious idea

The truth about **cons**

`cons` just makes a pair

- Often called a *cons cell*
- By convention and standard library, lists are nested pairs that eventually end with **`null`**

```
(define pr (cons 1 (cons #t "hi"))) ; '(1 #t . "hi")
(define lst (cons 1 (cons #t (cons "hi" null))))
(define hi (cdr (cdr pr)))
(define hi-again (car (cdr (cdr lst))))
(define hi-another (caddr lst))
(define no (list? pr))
(define yes (pair? pr))
(define of-course (and (list? lst) (pair? lst)))
```

Passing an *improper list* to functions like **`length`** is a run-time error

The truth about **`cons`**

So why allow improper lists?

- Pairs are useful
- Without static types, why distinguish **`(e1,e2)`** and **`e1::e2`**

Style:

- Use proper lists for collections of unknown size
- But feel free to use **`cons`** to build a pair
  - Though structs (like records) may be better

Built-in primitives:

- **`list?`** returns true for proper lists, including the empty list
- **`pair?`** returns true for things made by cons
  - All improper and proper lists except the empty list

cons cells are immutable

What if you wanted to mutate the *contents* of a cons cell?

- In Racket you cannot (major change from Scheme)
- This is good
  - List-aliasing irrelevant
  - Implementation can make **`list?`** fast since listness is determined when cons cell is created

Set! does not change list contents

This does *not* mutate the contents of a cons cell:

```
(define x (cons 14 null))
(define y x)
(set! x (cons 42 null))
(define fourteen (car y))
```

– Like Java's **`x = new Cons(42,null)`**, *not* **`x.car = 42`**

mcons cells are mutable

Since mutable pairs are sometimes useful (will use them soon), Racket provides them too:

- **`mcons`**
- **`mcar`**
- **`mcdr`**
- **`mpair?`**
- **`set-mcar!`**
- **`set-mcdr!`**

Run-time error to use **`mcar`** on a cons cell or **`car`** on an mcons cell

Delayed evaluation

For each language construct, the semantics specifies when subexpressions get evaluated. In ML, Racket, Java, C:

- Function arguments are *eager* (call-by-value)
  - Evaluated once before calling the function
- Conditional branches are not eager

It matters: calling **`factorial-bad`** never terminates:

```
(define (my-if-bad x y z)
  (if x y z))

(define (factorial-bad n)
  (my-if-bad (= n 0)
             1
             (* n (factorial-bad (- n 1)))))
```

Thunks delay

We know how to delay evaluation: put expression in a function!

– Thanks to closures, can use all the same variables later

A zero-argument function used to delay evaluation is called a *thunk*

– As a verb: *thunk the expression*

This works (but it is silly to wrap **`if`** like this):

```
(define (my-if x y z)
  (if x (y) (z)))

(define (fact n)
    (my-if (= n 0)
           (lambda() 1)
           (lambda() (* n (fact (- n 1))))))
```

The key point

- Evaluate an expression **`e`** to get a result:

```
e
```

- A function that *when called*, evaluates **`e`** and returns result
  - Zero-argument function for "thunking"

```
(lambda () e)
```

- Evaluate **`e`** to some thunk and then call the thunk

```
(e)
```

- Next: Powerful idioms related to delaying evaluation and/or avoided repeated or unnecessary computations
  - Some idioms also use mutation in encapsulated ways

Avoiding expensive computations

Thunks let you skip expensive computations if they are not needed

Great if take the true-branch:

```
(define (f th)
  (if (…) 0 (…  (th) …)))
```

But worse if you end up using the thunk more than once:

```
(define (f th)
  (… (if (…) 0 (… (th) …))
     (if (…) 0 (… (th) …))
     …
     (if (…) 0 (… (th) …))))
```

In general, might not know many times a result is needed

Best of both worlds

Assuming some expensive computation has no side effects, ideally we would:

- Not compute it *until needed*
- *Remember the answer* so future uses complete immediately

Called *lazy evaluation*

Languages where most constructs, including function arguments, work this way are *lazy languages*

- Haskell

Racket predefines support for *promises*, but we can make our own

- Thunks and mutable pairs are enough… [Friday]