CS 251 Spring 2020
Principles of Programming Languages
Ben Wood

WELLESLEY

Local Bindings and Scope

+let.rkt

Topics

- Control scope with local bindings
- Shadowing
- Scope sugar
- Nested function bindings
- Avoid duplicate computations
  - style and convenience
  - efficiency (*big-O*)

`let` expressions

Interchangeable: (), [], or {}

Syntax: `(let ([x1 e1] … [xn en]) e)`

Each ***xi*** is any *variable*. ***e*** and each ***ei*** are any *expressions.*

Evaluation:

1. Under the current dynamic environment, E, evaluate e1 through en to values v1, …, vn.
2. The result is the result of evaluating e under the environment, E, extended with bindings x1 ↦ v1, …, xn ↦ vn.

$$\frac{E \vdash e1 \downarrow v1 \quad \dots \quad E \vdash en \downarrow vn \quad x1 \mapsto v1, \dots, xn \mapsto vn, E \vdash e \downarrow v}{E \vdash (\texttt{let}\ ([x1\ e1]\ \dots\ [xn\ en])\ e) \downarrow v}\ [\text{let}]$$

`let` *expressions*

```
(+ (let ([x 1]) x)
   (let ([y (let ([a 2]) a)]
         [z 4])
     (- z y)))
```

`let` expressions control *scope.*

Scope of a binding = area of program that is evaluated while that binding is in environment.

Visualize scope via ***lexical contours***.

```
(define add-n  (lambda ( x ) (+  n  x )) )
(define add-2n (lambda ( y ) (add-n (add-n  y ))) )
(define n 17)
(define (f z)
        (let ([ c (add-2n z ) ]
              [ d (- z 3)     ])
          (+ z (* c d )))     ) )
```


`let` expressions control *scope.*

Let expression bindings are in the environment ***only*** during evaluation of the body.

Errors: cannot use x or y outside scope of bindings.

```
; E = .
(+ (let ([x   4]
         [y  (* 2 x)])
     ; E = x↦4, y↦8, .
     (+ x y)
   )
   ; E = .
   (* x y))
```


Shadowing

```
; E = .
(let ([x 2])
  ; E = x↦2, .
  (+ x
     (let ([x (* x x)])
       ; E = x↦4, x↦2, .
       (+ x 3)
     ) )
; E = .
```


`and` and `or` are sugar!

```
(and e1 e2)
```

desugars to

```
(if e1 e2 #f)
```

```
(or e1 e2)
```

desugars to

where `x1` is not used (without first being bound) in `e2` (easiest: "fresh" identifier used nowhere in entire program)

```
(let ([x1 e1])
  (if x1 x1 e2))
```

`let` is sugar!

Syntax: `(let ([xi e1] … [xn en]) e)`

Each *xi* is any *variable*. *e* and each *ei* are any *expressions*.

Evaluation:

1. Under the current dynamic environment, E, evaluate e1 through en to values v1, …, vn.
2. The result is the result of evaluating e under the environment, E, extended with bindings x1 ↦ v1, …, xn ↦ vn.

$$\frac{\texttt{E} \vdash \texttt{e1} \downarrow \texttt{v1} \quad \ldots \quad \texttt{E} \vdash \texttt{en} \downarrow \texttt{vn} \quad \texttt{x1} \mapsto \texttt{v1}, \ldots, \texttt{xn} \mapsto \texttt{vn}, \texttt{E} \vdash \texttt{e} \downarrow \texttt{v}}{\texttt{E} \vdash \texttt{(let ([x1 e1] … [xn en]) e)} \downarrow \texttt{v}}\ [\text{let}]$$

`let` is sugar!

`(let ([x1 e1] … [xn en]) e)`

desugars to

`((lambda (x1 … xn) e) e1 … en)`

Example:

`(let ([x (* 3 5)]) (+ x x))`

desugars to

`((lambda (x) (+ x x)) (* 3 5))`

Local function bindings

```
(define (quad x)
    (let ([square (lambda (x) (* x x))])
        (square (square x))))
```

Private helper functions bound locally can be good style.

Need `letrec` to allow recursion*.

```
(define (count-up-from-1 x)
    (letrec
      ([count (lambda (from to)
                (if (= from to)
                    (cons to null)
                    (cons from
                          (count (+ from 1) to))))])
      (count 1 x)))
```

*Not just lambda sugar. We will wait to define it precisely later.

Better style:

```
(define (count-up-from-1 x)
  (letrec
    ([count-to-x
       (lambda (from)
               (if (= from x)
                   (cons x null)
                   (cons from
                         (count-to-x (+ from 1) x))))])
    (count-to-x 1)))
```

- Functions can use bindings in the environment where they are defined: `count-to-x` can use `x`.
- Unnecessary parameters are usually bad style:
  - `to` in previous example

Nested functions: style

Good style to define helper functions inside the functions they help if they are:

- Unlikely to be useful elsewhere
- Likely to be misused if available elsewhere
- Likely to be changed or removed later

Trade-off in code design:

- reusing code saves effort and avoids bugs
- makes the reused code harder to change later

Avoid repeated recursion

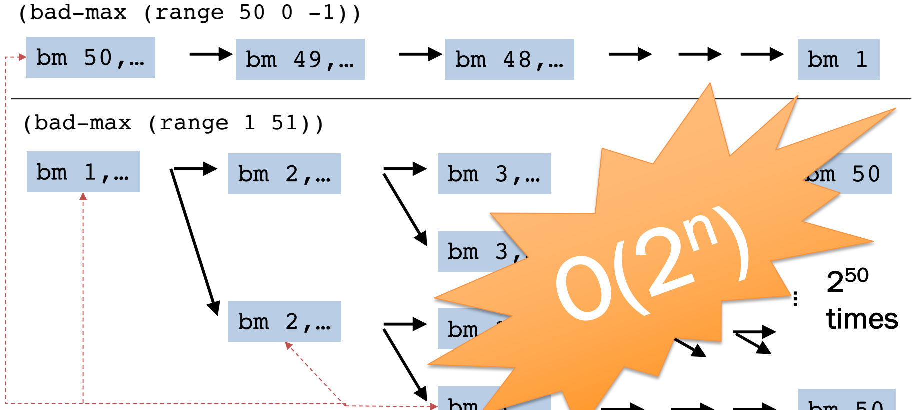
Consider this code and the recursive calls it makes

- Ignore calls to `first`, `rest`, and `null?` (small constant amounts of work)

```
(define (bad-max xs)
   (if (null? xs)
       null ; not defined on empty list
       (if (null? (rest xs))
           (first xs)
           (if (> (first xs)
                  (bad-max (rest xs)))
               (first xs)
               (bad-max (rest xs))))))
```


Fast vs. unusable

```
(if (> (first xs)
       (bad-max (rest xs)))
    (first xs)
    (bad-max (rest xs)))
```



Assume 10^{-7} seconds each

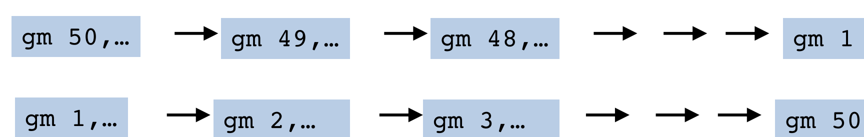
Then: 50 x 10^{-7} sec **vs** 1.12 x 10^{8} sec = 3.5 years

`(bad-max (list 1 2 … 100))` takes > 4 x 10^{15} years.

Our sun is predicted to die in about 5 x 10^{9} years.

Efficient max

```
(define (good-max xs)
   (if (null? xs)
       null ; not defined on empty list
       (if (null? (first xs))
           (first xs)
           (let ([rest-max (good-max (rest xs))])
               (if (> (first xs) rest-max)
                   (first xs)
                   rest-max)))))
```



Efficient and concise max

```
(define (maxlist xs)
    (if (null? xs)
        null ; not defined on empty list
        (max (first xs) (maxlist (rest xs)))))

; even better implementations to come later
```