Local definitions and lexical scope

Corky Cartwright

Vivek Sarkar

Department of Computer Science

Rice University

Top-Level Definitions

We have learned three kinds of definitions thus far:

1. Function definitions, *e.g.*,
   `(define (f x) (+ x 1))`
2. Variable (constant) definitions, *e.g.*,
   `(define two (f 1))`
3. Structure definitions, *e.g.*,
   `(define-struct pair (left right))`

They appear in Dr. Scheme's **`Definitions`** window and are called *top-level definitions*

`local` Expressions

A `local` *expression* groups together a set of definitions for use in a subcomputation:

`(local (`***def***$_1$ ***def***$_2$ … ***def***$_n$`)` ***exp***`)`

- ***exp*** is an arbitrary expression
- ***def***$_i$ is a definition in the set
- the variables defined in ***def***$_1$ ***def***$_2$ … ***def***$_n$ are distinct and only exist (are available for use) within the `local` expression *i.e.*, within ***def***$_1$ ***def***$_2$ … ***def***$_n$ and ***exp***

Simple Examples

```
(define x 3)                 ;; top-level definition
(local [(define x 3)] (+ x 1)) ;; local expression
(define (f x) (+ x 1))       ;; top-level definition

(local [(define x 2)         ;; local definitions
        (define (f x) (+ x 1))]
   (f x))                    ;; body

(+ (local [(define x 3)      ;; embedded local-expression
           (define (f x) (+ x 1))]
     (f x))
   1)
```

Some Incorrect Examples

- What’s wrong with following expressions?

```
(local [(define x 1)])
(local [(define x 1)
             (define x 2)]
   x)
(local [(define x 1)
           (define f (+ x 1))]
  (f x))
```

Why local?

Reason 1: Avoid namespace pollution

```
;; sort: list-of-numbers -> list-of-number
;; (sort lon) returns the elements of lon is ascending order
(define (sort alon)
  (cond
       [(empty? alon) empty]
    [(cons? alon) (insert (first alon)(sort (rest alon)))]))

;; insert: number list-of-numbers (sorted) -> list-of number
;; (insert n lon) assumes lon is in ascending order and returns a
;; a list containing n and the elements of lon in ascending order

(define (insert an alon)
  (cond [(empty? alon) (list an)]
        [else (if (<= an (first alon))
                  (cons an alon)]
                  (cons (first alon) (insert an (rest alon))))]))
```

Why local?

- Reason 1: Avoid namespace pollution (cont.)

```
;; sort: list-of-numbers -> list-of-numbers
(define (sort alon)
   (local
     [;; insert: number list-of-numbers (sorted) -> list-of numbers
      (define (insert an alon)
        (cond [(empty? alon) (list an)]
              [else (if (<= an (first alon))
                        (cons an alon)]
                        (cons (first alon)
                              (insert an (rest alon))))]))]
     (cond [(empty? alon) empty]
           [(cons? alon) (insert (first alon) (sort (rest alon)))]))
```

Why `local`?

Reason 1: Avoid namespace pollution

```
(define (mainFun x) exp)
(define (auxFun1 ...) exp1)
(define (auxFun2 ...) exp2)
```

⇓

```
 (define (mainFun x)
   (local [(define (minFun x) exp)
           (define (auxFun1 …) exp1)
           (define (auxFun2 …) exp2)]
     (mainFun x)))
```

Why local?

Reason 2: Avoid repeated computation

```
;; max-num: list-of-number -> number
;; (max=num lon) returns the largest number n in lon;
;;   throws an error if lon is empty
(define (max-num x lon)
  (cond
    [(empty? Lop) …]
    [else ... (first lon)
          ... (max-num x (rest lon)) ...]))
```

Why local?

Reason 2: Avoid repeated computation

```
(define (max-num lon)
    (cond
     [(empty? Lon)
      (error "max-num applied to empty list")]
     [else
       (if (or (empty? (rest lon))
               (>= (first lon) (max-num (rest lon))))
           (first lon)
           (max-num (rest lon)))]))
```

repeated work

Why local?

Reason 2: Avoid repeated computation

```
(define (max-num lon)
  (cond
    [(empty? Lon)
     (error “max-num applied to empty list”)]
    [else
      (if (empty? (rest lon))
          (first lon)
          (local [(define rest-max (max-num (rest lon)))]
             (if (> (first lon) rest-max)
                 (first lon)
                 rest-max))))]))
```

Why local?

Reason 3: Naming complicated expressions

```
;; mult10 : list-of-digits  ->  list-of-numbers
;; creates a list of numbers by multiplying each digit in alod
;; by (expt 10 p) where p is the number of digits that follow
;; This is bad code used only as an example.  Good code
;; requires refactoring techniques we haven't learned yet.

(define (mult10 alod)
  (cond [(empty? alod) empty]
        [else (cons (* (expt 10 (length (rest alod)))
                       (first alod))
                    (mult10 (rest alod)))]))
```

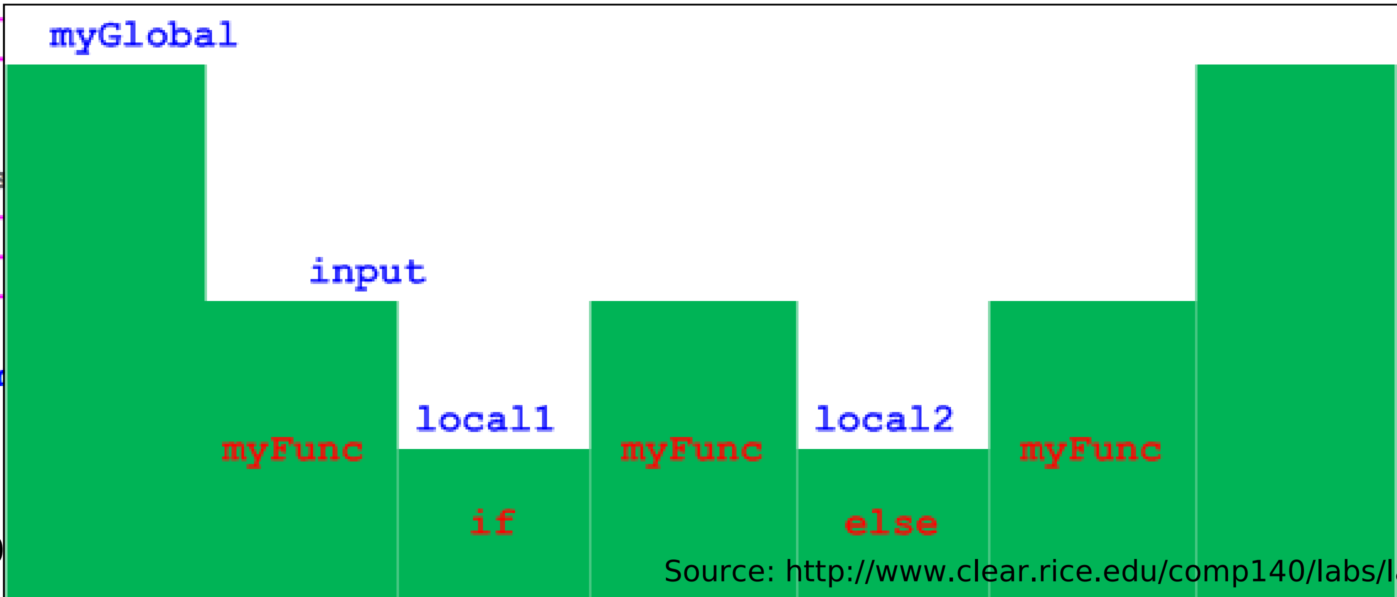
Why `local`?

- Reason 3: Naming complicated expressions

```
;; mult10 : list-of-digits  ->  list-of-numbers
;; creates a list of numbers by multiplying each digit in alod
;; by (expt 10 p) where p is the number of digits that follow
;; This is bad code used only as an example.  Good code
;; requires refactoring techniques we haven't learned yet.

(define (mult10 alod)
  (cond [(empty? alod) empty]
        [else (local [(define a-digit (first alod))
                      (define the-rest (rest alod))
                      (define p (length the-rest))]
                 (cons (* (expt 10 p) a-digit) (mult10 the-rest))]))
```

Recap of Variable Scopes from COMP 140

```
myGlobal = 42

def myFunc(input):
    print "myFunc: input = ", input
    print "myFunc: myGlobal = ", myGlobal # global variable visible here
    # neither local1 nor local2 are accessible here.
    if input > 0:
        local1 = 100
        # cannot access local2 from here.
        print "myFunc-if: local1 = ", local1
        print "myFunc-
        print "myFunc-
    else:
        local2 = -100
        # cannot acces
        print "myFunc-
        print "myFunc-
        print "myFunc-

print "myGlobal = ", m
myFunc(5)
myFunc(-5)
```



Source: http://www.clear.rice.edu/comp140/labs/l

Variables and Scope in Scheme

- Example:

$$\texttt{(local ((define answer}_1\texttt{ 42)]}$$
$$\qquad\texttt{(define (f}_2\texttt{ x}_3\texttt{) (+ 1 x}_4\texttt{)))}$$
$$\texttt{(f}_5\texttt{ answer}_6\texttt{))}$$

- Variable occurrences: 1-6
  - Binding (or defining) occurrences: 1,2,3
  - Use occurrences: 4,5,6
  - Scope = code region where a definition may be used
- Scopes of definitions
  - 1:?
  - 2:?
  - 3:?

Variables and Scope

- What will g evaluate to?

```
(define x 0)
(define f x)
(define g
  (local ((define x 1)) f))
```

Renaming

- Example:

```
    (local [(define answer_1 42)
            ((define (f_2 x_3) (+ 1 x_4))]
      (f_5 answer_6))
```

- Which variable occurrences can be renamed within the local expression?
- Use the same name for “binding occurrence” and all its “use occurrences”.
- Local variables can safely be renamed (no change to the answers produced by a program) without changing anything in the surrounding program.
- What name choices can be used? Any name that does not clash with variable names already visible in same scope. A “fresh” variable name.

Renaming

Example:

```
 (local [(define answer 42)
         (define (f x) (+ 1 x))]
    (f answer))
```

=>

```
 (local [(define answer_0 42)
         (define (f_0 x) (+ 1 x))]
    (f_0 answer_0))
```

We must rename all occurrences of a variable, both its *binding* occurrence and its *use* occurrences. In the preceding example, both **`answer`** and **`f`** have only one *use* occurrence. (Every variable has exactly one *binding* occurrence since each *binding* occurrence *defines* a new variable.) We are using the same underscore number convention for renaming as the DrScheme stepper.

Renaming

Recall our example:

```
 (local [(define answer 42)
         (define (f x) (+ 1 x))]
   (f answer))
```

=>

```
 (local [(define answer_0 42)
         (define (f_0 x) (+ 1 x))]
   (f_0 answer_0))
```

We could also rename the function parameters within a `local` expression but it is not necessary for our purposes. We simply want to rename all of the variables (including function names) introduced in a `local`.

Renaming in Evaluating `local`

Idea: We can promote (move) the block of `define`s introduced in a `local` to the top level (like the other `define`s in our program) *provided* that rename the variables introduced in the `local` so that they cannot clash with variables already `define`d at the top level.

Rule: when the leftmost unevaluated expression is a `local`, rename the variables `define`d in the `local`, lift the block of `define`s in the renamed `local` to the top level, and replace the `local` expression by its renamed body.

Evaluating `local` Expressions

Recap: how do we (hand) evaluate Scheme programs with `local`?

- By (*i*) renaming all of the `define`d variables in the `local` (with *fresh* names to avoid any collisions with variables already defined at the top level), (*ii*) lifting the renamed local definitions to the top level, and (*iii*) replacing the `local` expression by its renamed body.

To express this law we need a new format for expressing rules. Why? Because lifting `local` definitions *augments* the set of definitions that constitute the *environment* in which evaluation takes place.

Hand Evaluation Example

```
(define x 2)                ;; top-level definition
;; local-expression as part of another expression
(+ (local [(define x 3) (define (f x) (+ x 1))]
     (f x))
 1)
=>
(define x 2)
(define x_0 3)
(define (f_0 x) (+ x 1)))   ;; parameters not renamed
(+ (f_0 x_0) 1)
=>
```

Hand Evaluation Example

```
(define x 2)
(define x_0 3)
(define (f_0 x) (+ x 1)))
(+ (f_0 3) 1)
=>
(define x 2)
(define x_0 3)
(define (f_0 x) (+ x 1)))
(+ (+ 3 1) 1)
=>
(define x 2)
(define x_0 3)
(define (f_0 x) (+ x 1)))
(+ 4 1)
```

Hand Evaluation Example

```
=>
(define x 2)
(define x_0 3)
(define (f_0 x) (+ x 1)))
(+ 4 1)
```

With `local` in the language, each step in the evaluation must carry the environment (the block of `define`s constituting the program) as well as the expression being evaluated.

Confused? Try using the stepper (the menu button shaped like a foot) on examples in DrScheme.

When naming can cause problems

Romeo, Romeo! wherefore art thou Romeo?

. . .

What's in a name? That which we call a rose by any other name would smell as sweet.

Romeo and Juliet (II, ii)