

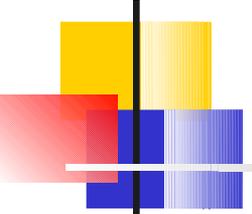
Local definitions and lexical scope

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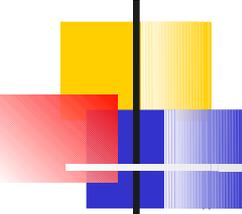


Top-Level Definitions

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 DrScheme's **Definitions** window and are called *top-level definitions*



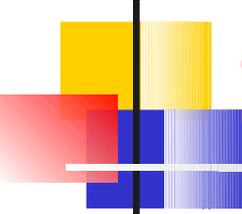
Local Expressions

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***
- The square brackets are used for clarity; parentheses are acceptable.

Note: **local** is not included in the Beginner language levels. Must use Intermediate level or higher.

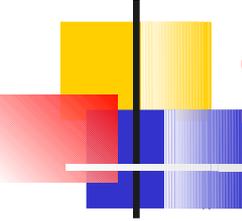


Simple Examples

```
(define x 3)                ;; top-level definition
(local [(define x 2)] (+ x 1)) ;; local expression
(define (f x) (+ x 1))      ;; top-level definition

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

(+ (local [(define x 2) ;; embedded local-expression
           (define (f x) (+ x 1))]
    (f x))
  1)
```



Some Incorrect Examples

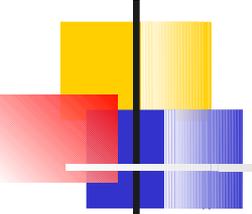
- What's wrong with following expressions?

```
(local [(define x 1)])
```

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

```
  x)
```

```
(+ (local [(define x 21)] (+ x x))  
  x)
```



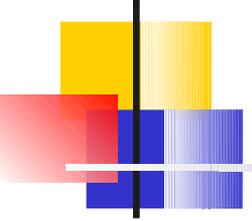
Why local?

Reason 1: Avoid namespace pollution

```
;; sort: list-of-numbers -> list-of-number
;; (sort lon) returns the elements of lon in 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))))]))
```



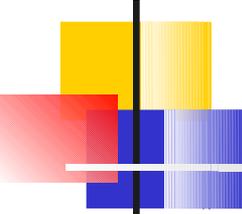
Why local?

- 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))))])]
  )
```

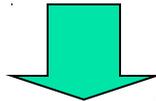
```
(cond [(empty? alon) empty]
      [(cons? alon) (insert (first alon) (sort (rest alon)))]))
```



Why local?

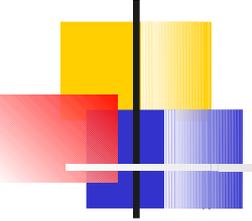
Reason 1: Avoid namespace pollution

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



```
(define (mainFun x)
  (local [(define (mainFun x) exp) ;; naming is ugly
          (define (auxFun1 ...) exp1)
          (define (auxFun2 ...) exp2)]
    (mainFun x)))
```

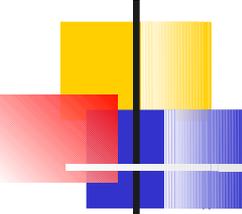
In the Scheme programming culture, the latter program is considered good style. But I no longer recommend this practice. Why? The functions defined inside **local** are not testable!



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 lon)
  (cond
    [(empty? lon) ... ]
    [else ... (first lon)
              ... (max-num (rest lon)) ... ]))
```

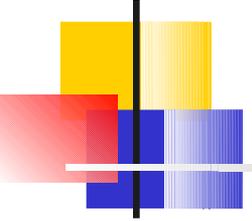


Why local?

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
when or fails

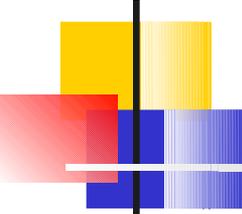


Why local?

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))))]))
```

I heartily endorse this use of `local`

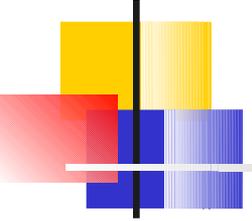


Why local?

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)))]))
```

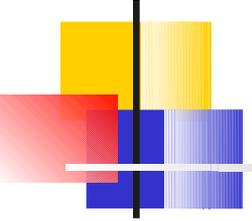


Why local?

Reason 3: Naming complicated expressions

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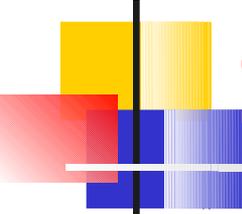
```
(define (mult10 alod)
  (cond [(empty? alod) empty]
        [else (local [(define a-digit (first alod))
                       (define the-rest (rest alod))
                       (define p (length the-rest))]
                   (cons (* (expt 10 p) a-digit) (mult10 the-rest)))]))
```



Why not local?

- Reason 1: Embedded functions are not testable!
- Reason 2: Embedded functions are not testable!
- Reason 3: Embedded functions are not testable!

Note: I no longer recommend moving function definitions to the local level unless they need to refer to local variables.



Variables and Scope in Scheme

Example:

```
(local [(define answer1 42)
        (define (f2 x3) (+ 1 x4))]
  (f5 answer6))
```

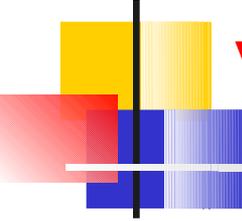
Variable occurrences: 1-6

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

Scopes of definitions (corresponding to binding occurrences)

1:?, 2:?, 3:?

DrScheme generates misleading diagnostics regarding scope in error messages.



Variables and Scope

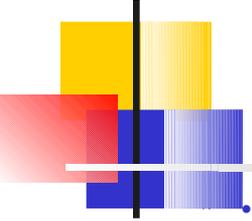
- What will g evaluate to?

```
(define x 0)
```

```
(define f x)
```

```
(define g
```

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

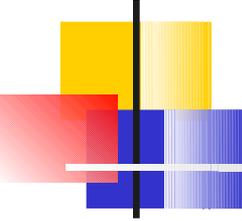


Renaming

Example:

```
(local [(define answer1 42)
        (define (f2 x3) (+ 1 x4))]
  (f5 answer6))
```

- 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

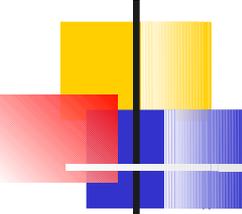
Example:

```
(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

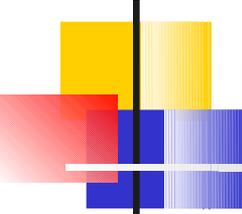
Recall our example:

```
(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)
```

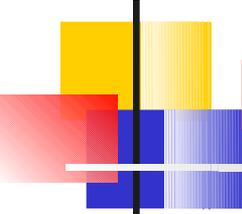
We could also rename the function parameters within a **local** expression but it is not necessary for our purposes. We simply want to rename all of the variables (including function names) introduced in a **local**.



Renaming in Evaluating `local`

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

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

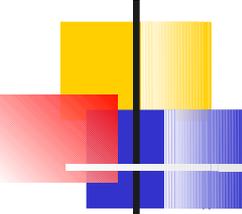


Evaluating `local` Expressions

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

- By (i) renaming all of the **defined** 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.



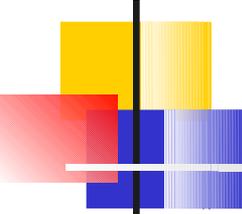
Hand Evaluation Example

```
(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

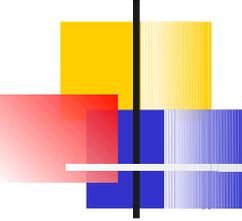
```
(define x 2)
(define x_0 3)
(define (f_0 x) (+ x 1))
(+ (f_0 3) 1)
```

=>

```
(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)
```



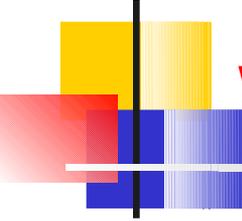
Hand Evaluation Example

=>

```
(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 **defines** 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)

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)
```

