CSCI 275: Programming Abstractions

Lecture 17: MiniScheme A, B & Environments
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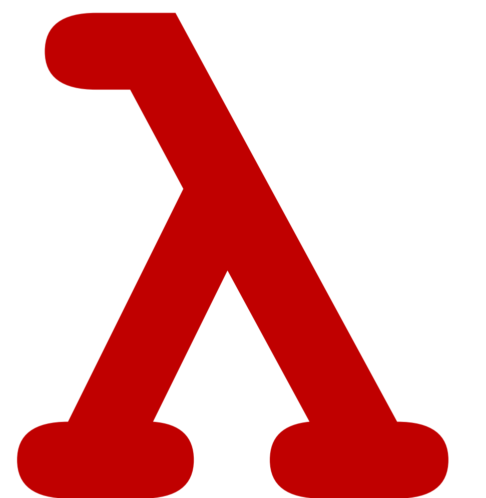


Questions? Concerns?

- Start thinking about MiniScheme project teams!
  - Three homeworks with the **same team**

Reminder: MiniScheme Project

You're going to *build an interpreter* for a subset of Scheme (called MiniScheme)

What does an interpreter do? *Executes* a program

Grammar

We need a way to specify the language of a valid program

Parser

We need to determine if a given program is valid (a tree!)

Evaluator

We need to evaluate a given program

Literals & Symbols

Numbers first

EXP → number   parse into `lit-exp`

We're going to need a data type to represent literal expression (and the only type of literals we have are numbers)

We're going to want something which gives

```
(lit-exp num) ; constructor
(lit-exp? exp) ; recognizer
(lit-exp-num exp) ; accessor
```

Parsing Numbers

```
(define (parse input)
  (cond [(number? input) (lit-exp input)]
        [else
          (raise-user-error
            'parse "Invalid syntax ~s" input)]))
```

Throwing errors is **important** in MiniScheme!

MiniScheme: *You don't need to implement it exactly the way I do in class, feel free to code how you'd like but you do need to use the name parse*

What does `(parse 15)` return, assuming the implementation we've discussed so far?

A. `15`

B. `(number 15)`

C. `(lit-exp 15)`

D. `(lit-exp "15")`

E. It's an error of some sort

Why is `(lit-exp 15)` what we want? In other words, why is there a data type for a number in our parser?

A. We just like to complicate things in this class

B. We parse *everything* into a tree, so we need a node to “hold” numbers/etc.

C. This relates to the grammar we talked about previously

D. More than one of the above

E. No idea

Errors

There are two types of errors we need to deal with in MiniScheme

- Implementation errors
  - Includes things like contract errors as well as your own explicit calls to `(error ‘foo “This is some error”)`
- Errors in the input (which is the MiniScheme expression that’s being evaluated)
  - Examples include bad syntax `(if x y)` or `(let)` for example

Handling input errors

You want to handle input errors differently than programming errors

```
(raise-user-error
   'some-symbol
   "A format string that can ~s arguments”
   "interpolate")
```

Running this will print an error message:

```
some-symbol: A format string that can "interpolate"
arguments
```

Example

```
(define (parse input)
  (cond [(number? input) (lit-exp input)]
        [else
          (raise-user-error
            'parse "Invalid syntax ~s" input)]))

> (parse "a string")
parse: Invalid syntax "a string"
> (parse '())
parse: Invalid syntax ()
> (parse 27)
(lit-exp 27)
```

Testing for input errors

The tests you write should include tests for invalid inputs

This is especially important for later parts of MiniScheme where you'll want to make sure your implementation correctly raises errors when special forms have the wrong number or types of arguments

The homework description explains how to write these tests in detail

The key is to use the RackUnit test function `test-exn` which tests that a 0-argument lambda raises a particular error

Evaluating literals

A starting interpreter:

```
(define (eval-exp tree e)
  (cond [(lit-exp? tree) (lit-exp-num tree)]
        [else
          (error 'eval-exp "Invalid tree: ~s"
                 tree)]))
```

What does `(eval-exp 15 empty-env)` return, assuming the implementation we've discussed so far)?

A. `15`

B. `(value 15)`

C. `(lit-exp 15)`

D. It's an error of some sort

```
(define (eval-exp tree e)
   (cond [(lit-exp? tree)
         (lit-exp-num tree)]
               [else
         (error 'eval-exp
   "Invalid tree: ~s" tree)]))
```

What does `(eval-exp (lit-exp 15) empty-env)` return, assuming the implementation we've discussed so far?

A. `15`

B. `(value 15)`

C. `(lit-exp 15)`

D. It's an error of some sort

```
(define (eval-exp tree e)
   (cond [(lit-exp? tree)
          (lit-exp-num tree)]
                 [else
          (error 'eval-exp
   "Invalid tree: ~s" tree)]))
```

Putting them together again

```
> (parse 107)
(lit-exp 107)

> (lit-exp 107)
(lit-exp 107)

> (eval-exp (lit-exp 107) empty-env)
107

> (eval-exp (parse 107) empty-env)
107
```

Recall: How to implement MiniScheme

For each new type of expression:

- Add a new data type
  - `ite-exp`
  - `let-exp`
  - etc.
- Modify `parse` to produce those
- Modify `eval-exp` to interpret them

EXP → number
| symbol
| (`if` *EXP EXP EXP*)
| (`let` (*LET-BINDINGS*) *EXP*)
| (`letrec` (*LET-BINDINGS*) *EXP*)
| (`lambda` (*PARAMS*) *EXP*)
| (`set!` symbol *EXP*)
| (`begin` *EXP**)
| (*EXP EXP**)
LET-BINDINGS → *LET-BINDING**
LET-BINDING → [symbol *EXP*]
PARAMS → symbol*

Remember: writing in Racket, implementing MiniScheme

Let's add some symbols (`'a`, `'+`, etc.) !

Grammar

EXP → number parse into `lit-exp`

  | symbol parse into `var-exp`

Data type for a variable reference expression might have:

```
(var-exp symbol) ;constructor
(var-exp? exp)   ;recognizer
(var-exp-symbol exp) ;accessor
```

Remember that numbers parse to `lit-exp` expressions.

What do we want `(parse 'x)` to return?

A. `10`

B. `(lit-exp 10)`

C. `(lit-exp 'x)`

D. `(var-exp 10)`

E. `(var-exp 'x)`

Let’s say we want to run

```
(eval-exp (parse `x) ... ).
```

What makes this different than evaluating a number?

How do we know what `x` means?

We bind things frequently in Racket: we make calls to `let`, we bind arguments to parameters of `lambda`s, etc.

Big Idea: to be able to find what a variable is bound to, we need a map from variables to their bound values. This is called an *environment*!

We’ve discussed this a bit before!

Recall that when Racket evaluates a variable, the result is the value that the variable is bound to

If we have `(define x 10)`, then evaluating `x` gives us the value `10`

If we have `(define (foo x) (- x y))`, then evaluating `foo` gives us the procedure `(lambda (x) (- x y))`, along with a way to get the value of `y` (which is hopefully defined!)

Racket needs a way to look up values that correspond to variables: an **environment**

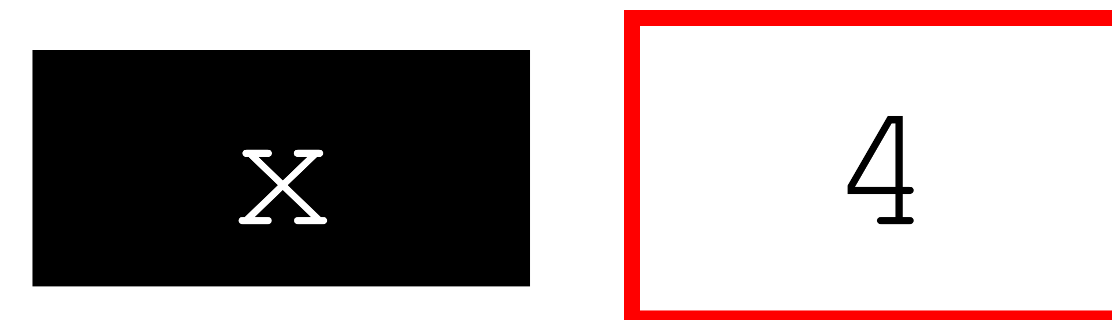
Your Task: Build an Environment!

You will build an environment (HW5) and there are rules for Racket about how variable binding works

- You have been mentally developing such mappings already as you trace through program evaluation!

Environments: Examples

```
(let ([x 2]
      [y 3])
  (let ([x 4])
    (+ x y)))
```



When we execute the following, what is the result?

```
(let ([x 2] [y 3])
    (let ([f (lambda (x) (+ x y))])
      (f 5)))
```

A. 8

B. 7

C. 5

D. Something else

Environment Operations

Two basic operations on environments, both of which you'll implement in MiniScheme:

1. **Look something up**
   - What is the binding of `x` right now?
2. **Add something to the environment**
   - Specifically, we'll do this by *extending* a previously constructed environment with new bindings

(1) Look Up in Environments

We need to look up the value bound to a symbol:

```
(let ([x 3])
  (let ([x 4])
    (+ x 5)))
```

should return 9 since the innermost binding of x is 4.

We say the inner `x` *shadows* the outer `x` – we need to account for this!

(2) Create New Environments

Create new environments by *extending* existing ones.

```
(let ([x 3])
  (+ (let ([x 10])
       (* 2 x))
     x))
=> 23
```

- If `E0` is the top-level environment, then the first `let` extends `E0` with a binding of `x` to 3
- If `E1` is the new environment, we write `E1 = E0[x ↦ 3]`
- The second let creates a new environment `E2 = E1[x ↦ 10]`
- The `(* 2 x)` is evaluated using `E2`
- The final `x` is evaluated using `E1`

Let `E0` be an environment with `x` bound to 10 and `y` bound to 23.

Let `E1 = E0[x ↦ 8, z ↦ 0]`

What is the result of looking up `x` in `E0` and `E1`?

A. `E0`: 10
   `E1`: 10

B. `E0`: 8
   `E1`: 8

C. `E0`: 10
   `E1`: 8

D. `E0`: 8
   `E1`: 10

E. `E1` can't exist because `z` isn't bound in `E0`

Let `E0` be an environment with `x` bound to 10 and `y` bound to 23.

Let `E1 = E0[x ↦ 8, z ↦ 0]`

What is the result of looking up `y` in `E0` and `E1`?

A. `E0`: 23
   `E1`: 23

B. `E0`: 23
   `E1`: error: `y` isn't bound in `E1`

C. It's an error in both because since `y` isn't bound in `E1`, it's not bound in `E0` any longer

D. None of the above

Let `E0` be an environment with `x` bound to 10 and `y` bound to 23.

Let `E1 = E0[x ↦ 8, z ↦ 0]`

What is the result of looking up `z` in `E0` and `E1`?

A. `E0`: 0
   `E1`: 0

B. `E0`: error: `z` isn't bound in `E0`
   `E1`: 0

C. None of the above