Scheme in Scheme

Why implement Scheme in Scheme

- Implementing a language is a good way to learn more about programming languages
- Interpreters are easier to implement than compilers, in general
- Scheme is a simple language, but also a powerful one
- Implementing it first in Scheme allows us to put off some of the more complex lower-level parts, like parsing and data structures
- While focusing on higher-level aspects

Lisp and Scheme are simple

- Simple syntax and semantics
- John McCarthy's original Lisp had very little structure:
  - Procedures CONS, CAR, CDR, EQ and ATOM
  - Special forms QUOTE, COND, SET and LAMBDA
  - Values T and NIL
- The rest of Lisp can be built on this foundation (more or less)

Meta-circular Evaluator

- "A meta-circular evaluator is a special case of a self-interpreter in which the existing facilities of the parent interpreter are directly applied to the source code being interpreted, without any need for additional implementation. Meta-circular evaluation is most common in the context of *homoiconic languages*".
- We'll look at an adaptation from

  Abelson and Sussman,Structure and Interpretation of Computer Programs, MIT Press, 1996.

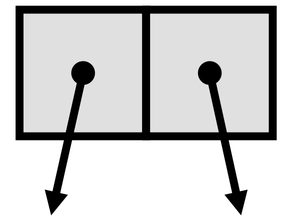
Meta-circular Evaluator

- Homoiconicity is a property of some programming languages
- From *homo* meaning the same and *icon* meaning representation
- A programming language is homoiconic if its primary representation for programs is also a data structure in a primitive type of the language itself
- Few examples: Lisp, Prolog, Snobol

Meta-circular Evaluator

- We’ll not do all of Scheme, just enough for you to understand the approach
- We can us the same approach for an interpreter for Scheme in Python
- To provide reasonable efficiency, we’ll use mutable-pairs

Mutable Pairs?



- Scheme calls a cons cell a pair
- Lisp always had special functions to change (aka *destructively* modify or *mutate*) the components of a simple cons cell
- Can you detect a sentiment there?
- RPLACA (RePLAce CAr) was Lisp's function to replace the car of a cons cell with a new pointer
- RPLACD (RePLAce CDr) clobbered the cons cell's cdr pointer

Lisp's rplaca and rplacd

```
GL% clisp
...
[1]> (setq l1 '(a b))
(A B)
[2]> (setq l2 l1)
(A B)
[3]> (rplaca l2 'foo)
(FOO B)
[4]> l1
(FOO B)
[5]> l2
(FOO B)
[6]> (rplacd l1 '(2 3 4))
(FOO 2 3 4)
[7]> l1
(FOO 2 3 4)
[8]> l2
(FOO 2 3 4)
```

Scheme's set-car! & set-cdr!

```
> (define l1 '(a b c d))
> l1
(a b c d)
> (set-car! l1 'foo)
> l1
(foo b c d)
> (set-cdr! l1 '(2 3))
> l1
(foo 2 3)
```

```
> (set-cdr! l1 l1)
> l1
#0=(foo . #0#)
> (cadr l1)
foo
> (caddr l1)
foo
> (cadddr l1)
foo
```

kicked out of R6RS

- Scheme removed set-car! and set-cdr! from the language as of R6RS
  - They played to their ideological base here
  - Or maybe just eating their own dog food
- **R6RS** is the Revised **6 Report on the Algorithmic Language Scheme
- R6RS does have a library, mutable-pairs, provides a new datatype for a mutable pair and functions for it
  - mcons, mcar, mcdr, mlist, …set-mcar!, set-mcdr!

Aside: PL standards

- Some languages are created/promoted by a company (e.g., Sun:Java, Microsoft:F#, Apple:Objective C)
- But for a language to really be accepted, it should be defined and maintained by the community
- And backed by a well-defined standard
- That may be supported by a recognized standards organizations (e.g., IEEE, ANSI, W3C, etc)

RnRS

- Scheme is standardized in the official IEEE standard and via a de facto standard called the *Revised^n Report on the Algorithmic Language Scheme*
- Or RnRS
- Common versions:
  - R5RS in 1998
  - R6RS in 2007

mutable-pairs

```
> (define l1 (cons 1 (cons 2 empty)))
> l1
(1 2)
> (define m1 (mcons 1 (mcons 2
   empty)))
> m1
{1 2}
> (car l1)
1
> (car m1)
. . car: expects argument of type
   <pair>; given {1 2}
```

```
> (mcar m1)
1
> (set-car! l1 'foo)
. . reference to undefined identifier:
set-car!
> (set-mcar! l1 'foo)
. . set-mcar!: expects type <mutable-
pair> as 1st argument, given: (1 2);
other arguments were: foo
> (set-mcar! m1 'foo)
> m1
{foo 2}
```

How to evaluate an expression

- We’ll sketch out some rules to use in evaluating an s-expession
- Then realize them in Scheme
- The (only) tricky part is representing an environment: binding symbols to values
  - Environments inherit from other environments, so we’ll consider an environment to be a set of frames
  - We’ll start with a global environment

Environment

- An environment is just a list of frames
- The first frame is the current environment, the second is the one it inherits from, the third is the one the second inherits from, etc.
- The last frame is the global or top level environment

Frame

- An environment frame is just an (unordered) collection of bindings
- A binding has two elements: a symbol representing a variable and an object representing its (current) value
- An environment might be represented as

```
( ( (x 100) (y 200) )
  ( (a 1) (b 2) (x 2) )
  ( (null '()) (empty '()) (cons …) …)
)
```

Eval an Atom

- **Self-Evaluating** - Just return their value
  - Numbers and strings are self evaluating
- **Symbol** - Lookup closest *binding* in the current environment and return its second element
  - Raise an error if not found

Eval a “special form”

Special forms are those that get evaluated in a special, non-standard way

- (quote X) – return X
- (define X B) – bind X to evaluation of B
- (lambda VARS BODY) - Make a procedure, write down VARS and BODY, do not evaluate
- (set! X Y) – find X binding name, eval Y and set X to the return value
- (if X Y Z) – eval X and then eval either Y or Z

Eval a procedure call

- **Primitive: (F . ARGS)**
  - Apply by magic...
- **User-defined: (F . ARGS)**
  - Make a new *environment frame*
  - Extend to procedures frame
  - Bind arguments to formal parameters
  - Evaluate procedure body in the new frame
  - Return its value

Our strategy

- We're implementing an interpreter for Scheme in Scheme
- The host language (Scheme) will do many details: data representation, reading, printing, primitives (e.g., cons, car, +)
- Our implementation will focus on a few key parts: eval, apply, variables and environments, user defined functions, etc.

McScheme interpreter in Scheme

http://cs.umbc.edu/331/f11/code/scheme/mcs/

- **mcs.ss**: simple Scheme subset
- **mcs_scope.ss**: larger Scheme subset
- **mcs_basics.ss**: 'library' of basic functions
- **readme.txt**: short intro text
- **session.txt**: example of McScheme in use

Limitations

- define can only assign a variable to a value, i.e., 1st arg must be a symbol. Define functions like:

  ```
  (define add1 (lambda (x) (+ x 1))
  ```

- lambda only allows one expression in body; for more use begin:

  ```
  (lambda (x) (begin (define y (* x x)) (* y y)))
  ```

- No set! to assign variables outside of the local environment (e.g., global variables)

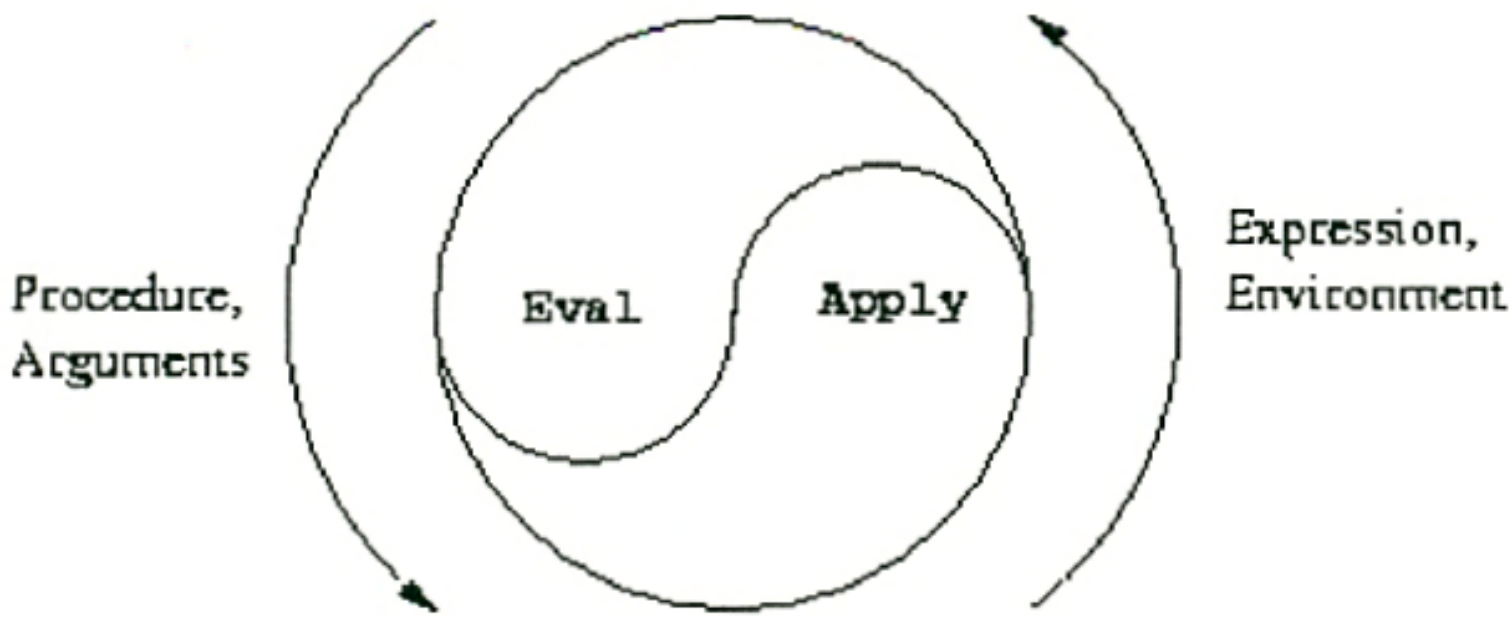
REPL

Here's a trivial read-eval-print loop:

```
(define (mcscheme)
  ;; mcscheme read-eval-print loop
  (printf "mcscheme> ")
  (mcprint (mceval (read) global-env))
  (mcscheme))

(define (mcprint x)
  ;; Top-level print: print x iff it's not void
  (or (void? x) (printf "~s~n" x)))
```

The Yin and Yang of Lisp



The eval and apply operations have been fundamental from the start

Simple mceval

```
(define (mceval exp env)
  (cond ((self-evaluating? exp) exp)
        ((symbol? exp) (lookup exp env))
        ((special-form? exp)
          (do-something-special exp env))
        (else (mcapply (mceval (car exp) env)
                       (map (lambda (e) (mceval e env))
                            (cdr exp))) ) ) )
```

mcapply

```
(define (mcapply op args)
  (if (primitive? op)
      (do-magic op args)
     (mceval (op-body op)
             (extend-environment
               (op-formals op)
               args
               (op-env op)))))
```

What's in a function?

- In Scheme or Lisp, the representation of a function has three parts:
  - A list of the names of its **formal parameters**
  - The expression(s) that make up the function's **body**, i.e. the code to be evaluated
  - The **environment** in which the function was defined, so values of non-local symbols can be looked up
- We might just represent a function as a list like

(procedure (x y) (+ (* 2 x) y) (… env …))

What's an environment

- An environment is just a list of environment **frames**
  - The last frame in the list is the global one
  - The nth frame in the list extends the n+1th
- An environment frame records two things
  - A list of **variables** bound in the environment
  - The **values** they are bound to
- Suppose we want to extend the global environment with a new local one where x=1 and y=2

Environment example

- Consider entering:
  - (define foo 100)
  - (define square (lambda (x) (* x x)))
  - (define x -100)
- The environment after evaluating the first three expressions would look like:

```
(  ( (x . -100)
     (square lambda (x)(* x x ))
     (foo . 100)
     …)
)
```

Environment example

- Consider entering:
  - (square foo)
- mcscheme evaluates *square* and *foo* in the current environment and pushes a new frame onto the environment in which x is bound to 100

```
(   (( x . 100 ))
   ((x . -100)
     (square lsmbda (x)(* x x ))
     (foo . 100) ... )
)
```

Lets look at the code

Take a look at the handout

mceval

```
(define (mceval exp env)
  (cond ((self-evaluating? exp) exp)
        ((symbol? exp) (lookup-variable-value exp env))
        ((quoted? exp) (cadr exp))
        ((assignment? exp) (eval-assignment exp env))
        ((definition? exp) (eval-definition exp env))
        ((if? exp) (eval-if exp env))
        ((lambda? Exp)
          (make-procedure (cadr exp) (cddr exp) env))
        ((begin? exp) (eval-sequence (cdr exp) env))
        ((application? exp)
         (mcapply (mceval (car exp) env)
            (map (lambda (x)(mceval x env)) (cdr exp))))
        (else (error "mceval: Unknown expression type" exp))))
```

mcapply

```
(define (mcapply procedure arguments)
  (cond ((primitive-procedure? procedure)
         (apply-primitive-procedure procedure arguments))
        ((defined-procedure? procedure)
         (eval-sequence
           (proc-body procedure)
           (extend-environment
             (proc-parameters procedure)
             arguments
             (proc-environment procedure))))
        (else (error "mceval: Unknown proc. type" procedure))))
```

Global Environment

```
(define global-environment '())

(define (setup-environment)
  (let ((initial-env
        (extend-environment primitive-proc-names
                            primitive-proc-objects
                            the-empty-environment)))
    (define-variable! 'empty '() initial-env)
    initial-env))

(define the-global-environment (setup-environment))
```

Extending an environment

```
(define (extend-environment vars vals base-env)
  (if (= (length vars) (length vals))
      (cons (make-frame vars vals) base-env)
      (if (< (length vars) (length vals))
          (error "Too many arguments supplied" vars vals)
          (error "Too few arguments supplied" vars vals))))

(define (make-frame variables values)
      (cons variables values))
```

Looking up a value

```
(define (lookup-variable-value var env)
 (define (env-loop env)
  (define (scan vars vals)
   (cond ((null? vars)
             (env-loop (enclosing-environment env)))
            ((eq? var (car vars)) (car vals))
            (else (scan (cdr vars) (cdr vals)))))
  (if (eq? env the-empty-environment)
     (error "Unbound variable" var)
     (let ((frame (car-frame env)))
       (scan (frame-variables frame)
            (frame-values frame)))))
 (env-loop env))
```

Defining a variable

```
(define (define-variable! var val env)
  (let ((frame (car-frame env)))
    (define (scan vars vals)
      (cond ((null? vars)
                   (add-binding-to-frame! var val frame))
                 ((eq? var (car vars))
                   (set-car! vals val))
                 (else (scan (cdr vars) (cdr vals)))))
    (scan (frame-variables frame)
          (frame-values frame))))
```

Setting a variable

```
(define (set-variable-value! var val env)
  (define (env-loop env)
    (define (scan vars vals)
      (cond ((null? vars) (env-loop (enclosing-environment env)))
            ((eq? var (car vars))  (set-car! vals val))
            (else (scan (cdr vars) (cdr vals)))))
    (if (eq? env the-empty-environment)
        (error "Unbound variable -- SET!" var)
        (let ((frame (car-frame env)))
          (scan (frame-variables frame)  (frame-values frame)))))
  (env-loop env))
```