Scheme

- Sources of Information:
  - Revised^4 Report on the Algorithmic Language Scheme. (Revised^5 Report also).
  - IEEE Standard for the Scheme Programming Language ($$$).
  - Books:
    - The Scheme Programming Language.
    - The Schematics of Computation.
    - The Little Schemer, The Seasoned Schemer.
  - MIT Scheme Users and Reference Manuals
  - The WWW.

Scheme Features

- functional programming language
  - program is expressed as function call(s).
- Structured data
  - strings, lists & vectors.
- garbage collection
- procedures are first-class data objects
- lexical scoping

Scheme Features (cont.)

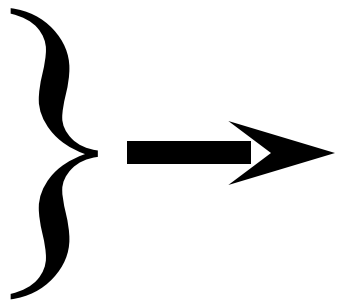
- programs share a common printed format with data.
  - programs can easily be used as data
- tail recursion
  - to support iteration efficiently
- continuations
  - goto !?!?!?
  - backtracking, multithreading

Scheme Features (cont.)

- Few syntactic forms
- syntactic extension is possible (R5)

Scheme Syntax

- keywords
- variables
- symbols
- structured forms
- constant data
- whitespace
- comments



Identifiers:

a-z

A-Z

0-9

? ! . + - * / < = > :

$ % ^ & _ ~

can't start with

numeric,+,- or .

Identifiers

- Identifiers must be delimited by whitespace, parentheses, double quote or the comment character ‘;’.
- No length limit.
- Case insensitive.

Structured Forms and List Constant Syntax

- *Structured forms* and list constants are enclosed within parentheses:

```
(a b c)
(* (- x 2) y)
```

- The empty list is written `()`

Boolean values

- Boolean value for true is written **`#t`**
- Boolean value for false is written **`#f`**

- Scheme conditional expressions treat **`#f`** as false and everything else as true.
- Some Scheme implementations treat **`()`** as false.

Whitespace and Comments

- Whitespace includes spaces, tabs and newlines.
- Whitespace length is not important (one space is the same as 100).
- Scheme expressions can span several lines.
- Comments appear between a ‘ ; ’ and the end of a line.

Some Naming Conventions

- Predicate names end in a **`?`**
  - examples: **`eq?  zero?  string=?`**
  - exceptions: **`=  <  >  <=  >=`**
- Procedures and syntactic forms that cause side effects end with **`!`**
  - example: **`set!`**
  - exceptions: **`write display read load`**

Scheme Expressions

- An expression can be a constant data object
  - string, number, symbol, list
  - examples: `17.5 3/5 "Hello World"`

- Or an expression can be a *procedure application:*

```
(foo 1 2)
```

application of the procedure foo.

Procedure Application

- Any procedure application is written in prefix form:

  (*procedure_name arg1 arg2* …)

- Arithmetic operations are not special, they are written in prefix form:

```
( + 10 20)
(* (* (* 52 7) 24) 60)
```

Precedence and Associativity

- Using prefix notation means that there are no rules for operator precedence or operator associativity!
- In a nested expression, innermost expressions are computed first (so the programmer determines the order of evaluation, not a bunch of rules).

Lists

- Lists are written as sequences of objects surrounded by parentheses.
- Examples:

```
(1 2 3 4)
("Hi" "Dave")
("One" 1)
(a b c (d e f))
```

List vs. Procedure Application

- A procedure application looks just like a list, so how does scheme known the difference ?
- We must tell scheme to treat a list as data rather than as a procedure application.
- The **`quote`** procedure forces a list to be treated as data: **`(quote (+ 3 4))`**
- This is so common we also can use the shorthand notation: **`'(+ 3 4)`**

List manipulation procedures

- **`car`** returns the first element of the list
- **`cdr`** returns the remainder of the list

```
(car '(a b c)) => a
(cdr '(a b c)) => (b c)
```

- **`cons`** constructs lists by adding a new element to the beginning of a list

```
(cons 'a '(b c)) => (a b c)
```

Proper and Improper Lists

- a *list* is a sequence of *pairs*.
- Each *pair's* **`cdr`** is the next *pair.*
- The **`cdr`** of the last pair in a proper list is the empty list.
- If the **`cdr`** of the last pair is not **`()`**, the list is an *improper list*.

Dotted Pair

- Improper lists are printed as a *dotted-pair*.

```
(cons 'a 'b) => (a . b)
(cdr '(a . b)) => b
(cons 'a '(b . c)) => (a b . c)
```

The procedure **`list`**

- **`list`** takes any number of arguments and builds a proper list:

```
(list 'a 'b 'c) => (a b c)
(list 'a) => (a)
(list ) => ()
(list '(a . b)) => ((a . b))
```

Expression Evaluation

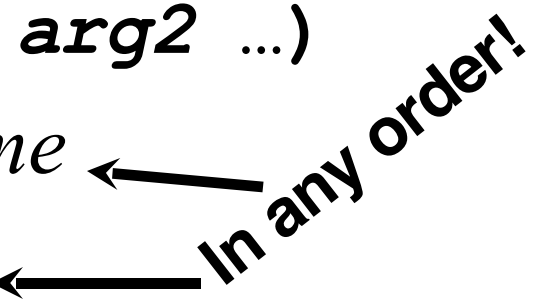
- Procedure application:

  (*procedure_name arg1 arg2* …)

  find the value of *procedure_name*

  find the value of *arg1, arg2, ...*

  apply the value of *procedure_name* to the values of *arg1, arg2, ...*



`quote` evaluation

- The rules for evaluation don't work for **`quote`** - why not ?
- **`quote`** does not evaluate the subexpression at all.
- **`quote`** is a different *syntactic form!*
- So far we've seen 3 syntactic forms:
  - procedure application, constant objects and quote expressions.

Variables

- during procedure application the value of variables is determined - so how do we set the value of a variable?
- The **`let`** syntactic form:

```
(let ((x 1))
  (+ x 3))  => 5

(let ((x 1) (y 2))
  (+ x y))  => 3
```

Let Expressions

- Let expressions include a list of variable-value pairs and a sequence of expressions (called the body).
- Let expressions are often used to simplify an expression that contains multiple copies of the same subexpression:

```
(let ((x (+ 2 2))) (* x x))=>16
```

Let Expressions

- Procedure names are no different than any other list element - so we can do this:

```
(let ((f +)) (f 1 2))  => 3
(let ((+ *)) (+ 2 3)) => 6
```

- The values bound by a **`let`** are only *visible* within the body of the **`let`**.

Let can be nested

```
(let ((x 1))
   (let ((x (+ x 1)))
      (+ x x))) => 4
```

The scope of each variable can be determined by the placement within the text of the program == lexical scoping.

Quiz

- What is the value of:

```
(let ((x 9))
   (* x
      (let ((x (/ x 3)))
         (+ x x))))
```

Lambda Expressions

- The syntactic form **`lambda`** creates a new procedure:

  `(lambda (var …) exp`$_1$ **`exp`**$_2$ **`…)`**

- The list of variables are the formal parameters and the expressions are the body.
- The variables in the var list are *bound* and all other variable are called *free*.

Lambda Expression Example

```
((lambda (x) (+ x x))
     (* 3 4))
```

The expression **`(lambda (x) (+ x x))`** defines an unnamed procedure which is then applied to the value **`(* 3 4)`.**

The result of this expression is 24.

Lambda Expression Quiz

```
(let ((foo (lambda (x) (+ x 1))))
   (let ((y 3))
      (foo y)))
```

Hint: In this case we are assigning a name to the procedure defined by the lambda expression.

Lambda Examples:

```
(let ((double (lambda (x)(+ x x))))
   (list (double (* 3 4))
         (double (/ 99 11))
         (double (- 2 7))))
=> (24 18 -10)
(let ((double-cons)
        (lambda (x) (cons x x)))
     (double-cons 'a))
 => (a . a)
```

Fancy Dancy

```
(let ((double-any
        (lambda (f x) (f x x))))
    (list (double-any + 13)
          (double-any cons 'a)))
=> (26 (a . a))
```

We can pass a procedure as a parameter!

Lexical Scoping

```
(let ((f (let ((x 'a))
           (lambda (y) (cons x y)))))
     (f 'b))
=> (a . b)
(let ((f (let ((x 'a))
           (lambda (y) (cons x y)))))
     (let ((x 'nota))
       (f 'b)))
=> (a . b)
```

Lambda formal parameters

- There are 3 possible forms for the formal parameter specification in a lambda expression:
  - proper list of variables: **`(x y z)`**
  - a single variable: **`y`**
  - an improper list of variables: **`(x y . z)`**

Lambda Formal Parameters

- Proper list - exactly *n* actual parameters must be supplied.
- Single variable - any number of parameters can be supplied and the variable is bound to a list of the values.
- Improper list - at least *n* actual parameters must be supplied, any extra are bound to the last formal parameter.

More Examples

```
(let ((f (lambda x x))) (f 1 2))
=> (1 2)

(let ((g (lambda (x . y)
           (list x y))))
     (g 1 2 3 4))
=> (1 (2 3 4))
```