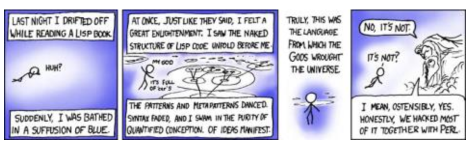
Lisp and Scheme I

Versions of LISP

- LISP is an acronym for LISt Processing language
- Lisp (b. 1958) is an old language with many variants
  - Fortran is only older language still in wide use
  - Lisp is alive and well today
- Most modern versions are based on Common Lisp
- Scheme is one of the major variants
  - We'll use Scheme, *not* Lisp, in this class
  - Scheme is used for CS 101 in some universities
- The essentials haven't changed much

Why Study Lisp?

- It's a simple, elegant yet powerful language
- You will learn a lot about PLs from studying it
- We'll look at how to implement a minimal version of Scheme
- Many features, once unique to Lisp, are now in "mainstream" PLs: Python, Javascript, Perl …
- It will expand your notion of what a PL can be
- Lisp is considered hip and esoteric among computer scientists



We lost the documentation on quantum mechanics. You'll have to decode the regexes yourself.

LISP Features

- **S-expression as the universal data type** – either an atom (e.g., number, symbol), or a list of atoms or sublists
- **Functional Programming Style** – computation done by applying functions to arguments, functions are first class objects, minimal use of side-effects
- **Uniform Representation of Data & Code** – (A B C D) can be interpreted as data (i.e., a list of four elements) or code (calling function 'A' to the three parameters B, C, and D)
- **Reliance on Recursion** – iteration is provided too, but recursion is considered more natural and elegant
- **Garbage Collection** – frees programmer's explicit memory management

What's Functional Programming?

- The FP paradigm: computation is applying functions to data
- Imperative or procedural programming: a program is a set of steps to be done in order
- FP eliminates or minimizes side effects and mutable objects that create/modify state
  - –E.g., consider f1(f2(a), f2(b))
- FP treats functions as objects that can stored, passed as arguments, composed, etc.

Pure Lisp and Common Lisp

- Lisp has a small and elegant conceptual core that has not changed much in almost 50 years.
- McCarthy's original Lisp paper defined all of Lisp using just **seven** primitive functions
- Common Lisp, developed in the 1980s as an ANSI standard, is large (>800 builtin functions), has most modern data-types, good programming environments, and good compilers

Scheme

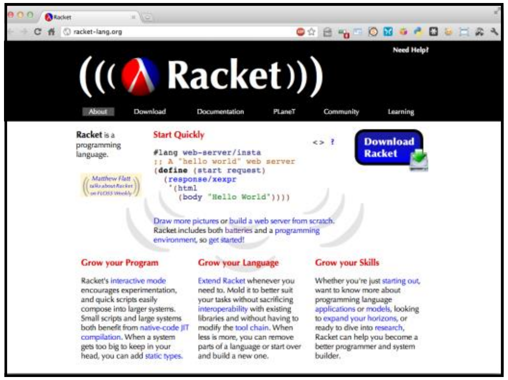
- Scheme is a dialect of Lisp that is favored by people who teach and study programming languages
- Why?
  - It's simpler and more elegant than Lisp
  - It's pioneered many new programming language ideas (e.g., continuations, call/cc)
  - It's influenced Lisp (e.g., lexical scoping of variables)
  - It's still evolving, so it's a good vehicle for new ideas

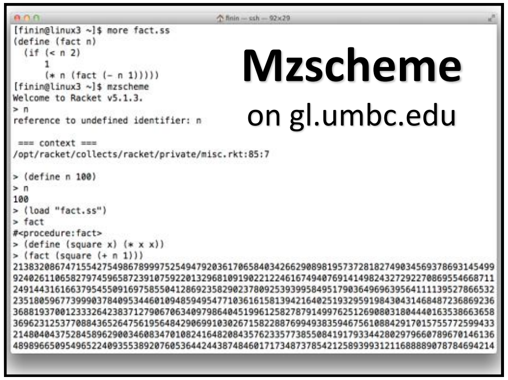
But I want to learn Lisp!

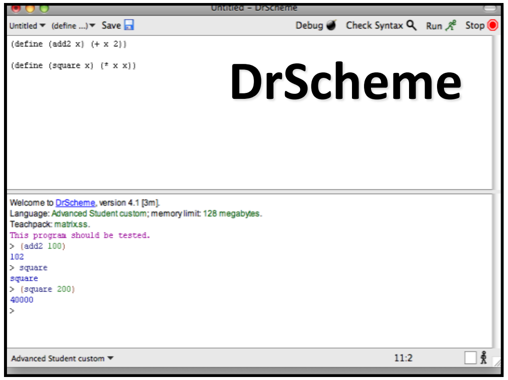
- Lisp is used in many practical systems, but Scheme is not
- Learning Scheme is a good introduction to Lisp
- We can only give you a brief introduction to either language, and at the core, Scheme and Lisp are the same
- We'll point out some differences along the way

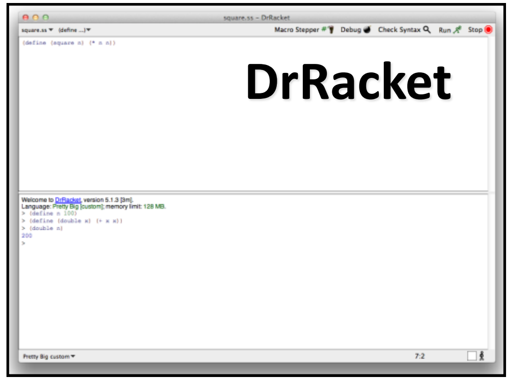
DrScheme and MzScheme

- We'll use the PLT Scheme system developed by a group of academics (Brown, Northeastern, Chicago, Utah)—now called Racket
- It's most used for teaching introductory CS courses
- MzScheme is the basic scheme engine and can be called from the command line and assumes a terminal style interface
- DrScheme is a graphical programming environment for Scheme









Informal Scheme/Lisp Syntax

- An *atom* can be an integer, or an identifier, or a string, or…
- A *list* is a left parenthesis, followed by zero or more S-expressions, followed by a right parenthesis
- An ***S-expression*** is an atom or a list
- Example: ()
- (A (B 3) (C) (( )))

Hello World

```
(define (helloWorld)
    ;; prints and returns the message.
    (printf "Hello World\n"))
```

Square

```
> (define (square n)
      ;; returns square of a numeric argument
      (* n  n))
> (square 10)
100
```

REPL

- Lisp and Scheme are interactive and use what is known as the "[read, eval, print loop]"
  - **While true**
    - **Read** one expression from the open input
    - **Evaluate** the expression
    - **Print** its returned value
- (define (repl) (print (eval (read))) (repl))

What is evaluation?

- We evaluate an expression producing a value
  - Evaluating "2 + sqrt(100)" produces 12
- Scheme has a set of rules specifying how to evaluate an s-expression
- We will get to these very soon
  - There are only a few rules
  - Creating an interpreter for scheme means writing a program to
    - read scheme expressions,
    - apply the evaluation rules, and
    - print the result

Built-in Scheme Datatypes

Basic Datatypes

- Booleans
- Numbers
- Strings
- Procedures
- Symbols
- Pairs and Lists

The Rest

- Bytes & Byte Strings
- Keywords
- Characters
- Vectors
- Hash Tables
- Boxes
- Void and Undefined

Lisp: T and NIL

- Since 1958, Lisp has used two special symbols: NIL and T
- NIL is the name of the empty list, ( )
- As a boolean, NIL means "false"
- T is usually used to mean "true," but…
- …anything that isn't NIL is "true"
- NIL is both an atom and a list
  - it's defined this way, so just accept it

Scheme: #t, #f, and '()

- Scheme cleaned this up a bit
- Scheme's boolean datatype includes #t and #f
- #t is a special symbol that represents true
- #f represents false
- In practice, anything that's not #f is true
- Booleans evaluate to themselves
- Scheme represents empty lists as the literal ( ) which is also the *value* of the symbol *null*
  - (define null '())

Numbers

- Numbers evaluate to themselves
- Scheme has a rich collection of number types including the following
  - Integers (42)
  - Floats (3.14)
  - Rationals: (/ 1 3) => 1/3
  - Complex numbers: (* 2+2i -2-2i) => 0-8i
  - Infinite precision integers: (expt 99 99) => 369…99 *(contains 198 digits!)*
  - And more…

Strings

- Strings are fixed length arrays of characters
  - "foo"
  - "foo bar\n"
  - "foo \"bar\""
- Strings are immutable
- Strings evaluate to themselves

Predicates

- A predicate (in any computer language) is a function that returns a boolean value
- In Lisp and Scheme predicates returns either #f or often something else that might be useful as a true value
  - The member function returns true iff its 1st argument is in the list that is its 2nd
  - (member 3 (list 1 2 3 4 5 6)) => (3 4 5 6))

Function calls and data

- A function call is written as a list
  - the first element is the name of the function
  - remaining elements are the arguments
- Example: (F A B)
  - calls function F with arguments A and B
- Data is written as atoms or lists
- Example: (F A B) is a list of three elements
  - Do you see a problem here?

Simple evaluation rules

- Numbers evaluate to themselves
- #t and #f evaluate to themselves
- Any other atoms (e.g., foo) represents variables and evaluate to their values
- A list of n elements represents a function call
  - e.g., (add1 a)
  - Evaluate each of the n elements (e.g., add1->a procedure, a->100)
  - Apply function to arguments and return value

Example

```
(define a 100)
> a
100
> add1
#<procedure:add1>
> (add1 (add1 a))
102
> (if (> a 0) (+ a 1)(- a 1))
103
```

- *define* is a *special form* that doesn't follow the regular evaluation rules
  - Scheme only has a few of these
- Define doesn't evaluate its first argument
- *if* is another special form
  - What do you think is special about if?

Quoting

- Is (F A B) a call to F, or is it just data?
- All *literal data* must be quoted (atoms, too)
- (QUOTE (F A B)) is the list (F A B)
  - QUOTE is not a function, but a **special form**
  - Arguments to a special form aren't evaluated or are evaluated in some special manner
- '(F A B) is another way to quote data
  - There is just one single quote at the beginning
  - It quotes *one* S-expression

Symbols

- Symbols are atomic names

  > 'foo
  foo
  > (symbol? 'foo)
  #t
- Symbols are used as names of variables and procedures
  - (define foo 100)
  - (define (fact x) (if (= x 1) 1 (* x (fact (- x 1)))))

Basic Functions

- car returns the head of a list
  (car '(1 2 3)) => 1
  (first '(1 2 3)) => 1 ;; for people who don't like car
- cdr returns the tail of a list
  (cdr '(1 2 3)) => (2 3)
  (rest '(1 2 3)) => (2 3) ;; for people who don't like cdr
- cons constructs a new list beginning with its first arg and continuing with its second
  (cons 1 '(2 3)) => (1 2 3)

CAR, CDR and CONS

- These names date back to 1958
  - Before lower case characters were invented
- CONS = CONStruct
- CAR and CDR were each implemented by a single hardware instruction on the IBM 704
  - CAR: Contents of Address Register
  - CDR: Contents of Decrement Register

More Basic Functions

- eq? compares two atoms for equality
  (eq? 'foo 'foo) => #t
  (eq? 'foo 'bar) => #f
  Note: eq? is just a pointer test, like Java's '='
- equal? tests two list structures
  (equal? '(a b c) '(a b c)) =#t
  (equal? '(a b) '((a b))) => #f
  Note: equal? compares two complex objects, like a Java object's equal method

Comment on Names

- Lisp used the convention (inconsistently) of ending *predicate* functions with a P
  - E.g., MEMBERP, EVENP
- Scheme uses the more sensible convention to use ? at the end such functions
  - e.g., eq?, even?
- Even Scheme is not completely consistent in using this convention
  - E.g., the test for list membership is *member* and not *member?*

Other useful Functions

- (null? S) tests if S is the empty list
  - (null? '(1 2 3)) => #f
  - (null? '()) => #t
- (list? S) tests if S is a list
  - (list? '(1 2 3)) =>#t
  - (list? '3) => #f

More useful Functions

- list makes a list of its arguments
  - (list 'A '(B C) 'D) => (A (B C) D)
  - (list (cdr '(A B)) 'C) => ((B) C)
- Note that the parenthesized prefix notation makes it easy to define functions that take a varying number of arguments.
  - (list 'A) => (A)
  - (list) => ( )
- Lisp dialects use this flexibility a lot

More useful Functions

- append concatenates two lists
  - (append '(1 2) '(3 4)) => (1 2 3 4)
  - (append '(A B) '((X) Y)) => (A B (X) Y)
  - (append '( ) '(1 2 3)) => (1 2 3)
- append takes any number of arguments
  - (append '(1) '(2 3) '(4 5 6)) => (1 2 3 4 5 6)
  - (append '(1 2)) => (1 2)
  - (append) => null
  - (append null null null) => null

If then else

- In addition to cond, Lisp and Scheme have an if special form that does much the same thing
- (if <test> <then> <else>)
  - (if (< 4 6) 'foo 'bar) => foo
  - (if (< 4 2) 'foo 'bar) => bar
  - (define (min x y) (if (< x y) x y))
- In Lisp, the else clause is optional and defaults to null, but in Scheme it's required

Cond

cond (short for conditional) is a special form that implements the *if ... then ... elseif ... then ... elseif ... then ...* control structure

```
(COND
    (condition1   result1 )      a clause
    (condition2   result2 )
    . . .
    (#t   resultN ) )
```

Cond Example

```
(cond ((not (number? x))
       0)
      ((< x 0)  0)
      ((< x 10)  x)
      (#t  10))
```

```
(if (not (number? x))
    0
    (if (<x 0)
        0
        (if (< x 10)
            x
            10)))
```

Cond is superfluous, but loved

- Any cond can be written using nested "if" expressions
- But once you get used to the full form, it's very useful
  - It subsumes the conditional and switch statements
- One example:

```
(cond ((test1 a)
         (do1 a)(do2 a)(value1 a))
       ((test2 a)))
```

- *Note: If **no** clause is selected, then cond returns #<void>*
- *It's as if every cond had a final clause like (#t (void))*

Defining Functions

(DEFINE (*function_name . parameter_list)*
  . function_body)

Examples:

```
;; Square a number
(define (square n) (* n n))

;; absolute difference between two numbers.
(define (diff x y)  (if (> x y)  (- x y) (- y x)))
```

Example: member

member is a built-in function, but here's how we'd define it

```
(define (member x lst)
   ;; x is a top-level member of a list if it is the first
   ;; element or if it is a member of the rest of the list
   (cond ((null? lst) #f)
         ((equal? x (car lst)) lst)
         (#t (member x (cdr lst)))))
```

Example: member

- We can also define it using if:

```
(define (member x lst)
   (if (null? lst)
      #f
      (if (equal? x (car lst))
         lst
         (member x (cdr lst)))))
```

- We could also define it using not, and & or

```
(define (member x lst)
 (and (not (null? lst))
      (or (equal? x (car lst))
        (member x (cdr lst)))))
```

Append concatenate lists

```
> (append '(1 2) '(a b c))
(1 2 a b c)
> (append '(1 2) '())
(1 2)
> (append '() '() '())
()
> (append '(1 2 3))
(1 2 3)
> (append '(1 2) '(2 3) '(4 5))
(1 2 2 3 4 5)
> (append)
()
```

- *Lists are immutable*
- *Append constructs new lists*

Example: define append

- (append '(1 2 3) '(a b)) => (1 2 3 a b)
- Here are two versions, using if and cond:

```
(define (append l1 l2)
   (if (null? l1)
      l2
      (cons (car l1) (append (cdr l1) l2))))

(define (append l1 l2)
   (cond ((null? l1) l2)
         (#t (cons (car l1) (append (cdr l1) l2)))))
```

Example: SETS

- Implement sets and set operations: union, intersection, difference
- Represent a set as a list and implement the operations to enforce uniqueness of membership
- Here is set-add

```
(define (set-add thing set)
  ;; returns a set formed by adding THING to set SET
  (if (member thing set) set (cons thing set)))
```

Example: SETS

- Union is only slightly more complicated

```
(define (set-union S1 S2)
  ;; returns the union of sets S1 and S2
  (if (null? S1)
     S2
     (set-add (car S1)
              (set-union (cdr S1) S2))))
```

Example: SETS

Intersection is also simple

```
(define (set-intersection S1 S2)
  ;; returns the intersection of sets S1 and S2
  (cond ((null? s1) nil)
        ((member (car s1) s2)
         (cons (car s1) (set-intersection (cdr s1) s2)))
        (#t (set-intersection (cdr s1) s2)))))
```

Reverse

- Reverse is another common operation on Lists
- It reverses the "top-level" elements of a list
  - Speaking more carefully, it constructs a new list equal to it's argument with the top level elements in reverse order.
- (reverse '(a b (c d) e)) => (e (c d) b a)

```
(define (reverse L)
  (if (null? L)
     null
     (append (reverse (cdr L)) (list (car L))))
```

Reverse is Naïve

- The previous version is often called naïve reverse because it's so inefficient
- What's wrong with it?
- It has two problems
  - The kind of recursion it does grows the stack when it does not need to
  - It ends up making lots of needless copies of parts of the list

We'll address these issues in a later class

Programs on file

- Use any text editor to create your program
- Save your program on a file with the extension .ss
- (load "foo.ss") loads foo.ss
- (load "foo.bar") loads foo.bar
- Each s-exprssion in the file is read and evaluated.

Comments

- In Lisp, a comment begins with a semicolon (;) and continues to the end of the line
- Conventions for ;;; and ;; and ;
- Function document strings:

```
(defun square (x)
  "(square x) returns x*x"
  (* x x))
```