Lisp and Scheme I

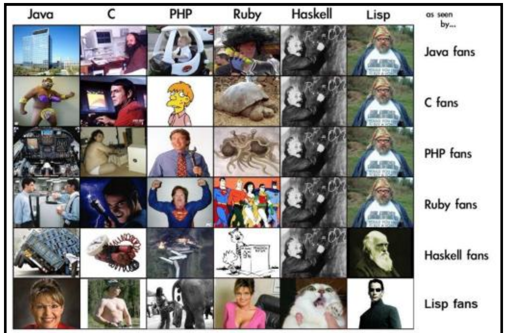
Versions of LISP

- 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 Scheme interpreter in Scheme and Python
- 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.



How Programming Language Fanboys See Each Others' Languages

LISP Features

- **S-expression as the universal data type** – either at 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!

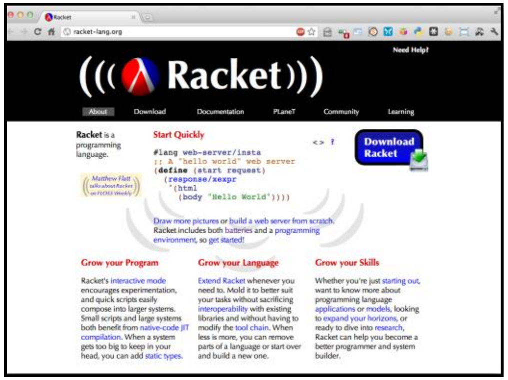
- Lisp is used in many practical systems, but Scheme is not
- Learning Scheme is a good introduction to Lisp
- We can only give you a brief introduction to either language, and at the core, Scheme and Lisp are the same
- We'll point out some differences along the way

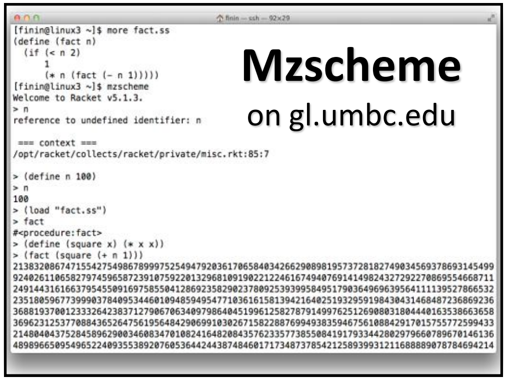
But I want to learn Clojure!

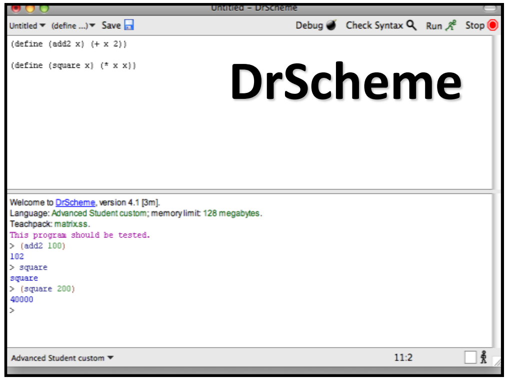
- Clojure is a new Lisp dialect that compiles to the Java Virtual Machine
- It offers advantages of both Lisp (dynamic typing, functional programming, closures, etc.) and Java (multi-threading, fast execution)
- We'll look at Clojure briefly later

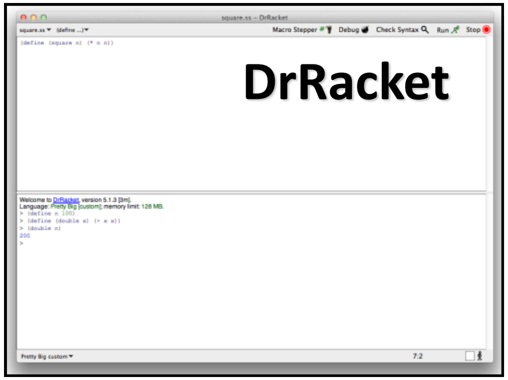
DrScheme and MzScheme

- We'll use the PLT Scheme system developed by a group of academics (Brown, Northeastern, Chicago, Utah)
- 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 it’s 1st argument is in the list that is it’s 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 listbeginning with it's first arg and continuing with it's 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                          a clause
    (condition1   result1 )
    (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)) list)
        (#t (member x (cdr lst)))))
```

Example: member

- We can also define it using if:

```
(define (member x lst)
   (if (null> lst)
      null
      (if (equal x (car lst))
         list
         (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
      (add-set (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)
         (set-intersection (cdr s1) s2))
        (#t (cons (car s1)
                  (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))))
```

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))
```