CS 242

Lisp

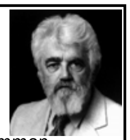
John Mitchell

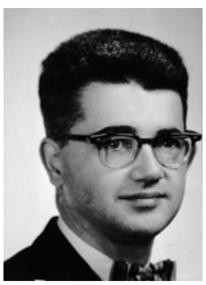
Reading: Chapter 3 Homework 1: due Oct 3

Lisp, 1960

- Look at Historical Lisp
  - Perspective
    - Some old ideas seem old
    - Some old ideas seem new
  - Example of elegant, minimalist language
  - Not C, C++, Java: a chance to think differently
  - Illustrate general themes in language design
- Supplementary reading (optional)
  - McCarthy, Recursive functions of symbolic expressions and their computation by machine, CACM, Vol 3, No 4, 1960. (see CS242 web site)

John McCarthy





- Pioneer in AI
  - Formalize common-sense reasoning
- Also
  - Proposed timesharing
  - Mathematical theory
  - ….
- Lisp

  stems from interest in symbolic computation (math, logic)

Lisp summary

- Many different dialects
  - Lisp 1.5, Maclisp, …, Scheme, ...
  - CommonLisp has many additional features
  - This course: a fragment of Lisp 1.5, approximately

    But ignore static/dynamic scope until later in course
- Simple syntax

  (+ 1 2 3)

  (+ (* 2 3) (* 4 5))

  (f x y)

  Easy to parse (Looking ahead: programs as data)

Atoms and Pairs

- Atoms include numbers, indivisible "strings"

  <atom> ::= <smbl> | <number>

  <smbl> ::= <char> | <smbl><char> | <smbl><digit>

  <num> ::= <digit> | <num><digit>
- Dotted pairs
  - Write (A . B) for pair
  - Symbolic expressions, called *S-expressions*:

    <sexp> ::= <atom> | (<sexp> . <sexp>)

◆ Note on syntax
- Book uses some kind of pidgin Lisp
- Handout provides executable alternative, so examples run in Scheme
- In Scheme, a pair prints as (A . B), but (A . B) is not an expression

Basic Functions

- Functions on atoms and pairs:

  cons car cdr eq atom
- Declarations and control:

  cond lambda define eval quote
- Example

  (lambda (x) (cond ((atom x) x) (T (cons 'A x))))

  function f(x) = if atom(x) then x else cons("A",x)
- Functions with side-effects

  rplaca rplacd

Evaluation of Expressions

- Read-eval-print loop
- Function call (function arg_1 … arg_n)
  - evaluate each of the arguments
  - pass list of argument values to function
- Special forms do not eval all arguments
  - Example (cond (p_1 e_1) … (p_n e_n))
    - proceed from left to right
    - find the first p_i with value true, eval this e_i
  - Example (quote A) does not evaluate A

Examples

(+ 4 5)
  expression with value 9
(+ (+ 1 2) (+ 4 5))
  evaluate 1+2, then 4+5, then 3+9 to get value
(cons (quote A) (quote B))
  pair of atoms A and B
(quote (+ 1 2))
  evaluates to list (+ 1 2)
'(+ 1 2)
  same as (quote (+ 1 2))

McCarthy's 1960 Paper

- Interesting paper with
  - Good language ideas, succinct presentation
  - Some feel for historical context
  - Insight into language design process
- Important concepts
  - Interest in symbolic computation influenced design
  - Use of simple machine model
  - Attention to theoretical considerations
    Recursive function theory, Lambda calculus
  - Various good ideas: Programs as data, garbage collection

Motivation for Lisp

- Advice Taker
  - Process sentences as input, perform logical reasoning
- Symbolic integration, differentiation
  - expression for function --> expression for integral
    (integral '(lambda (x) (times 3 (square x))))
- Motivating application part of good lang design
  - Keep focus on most important goals
  - Eliminate appealing but inessential ideas

Lisp	symbolic computation, logic, experimental prog.
C	Unix operating system
Simula	simulation
PL/1	"kitchen sink", not successful in long run

Execution Model (Abstract Machine)

- Language semantics must be defined
  - Too concrete
    - Programs not portable, tied to specific architecture
    - Prohibit optimization (e.g., C eval order *undefined* in expn)
  - Too abstract
    - Cannot easily estimate running time, space
- Lisp: IBM 704, but only certain ideas …
  - Address, decrement registers -> cells with two parts
  - Garbage collection provides abstract view of memory

Abstract Machine

- Concept of abstract machine:
  - Idealized computer, executes programs directly
  - Capture programmer's mental image of execution
  - Not too concrete, not too abstract
- Examples
  - Fortran
    - Flat register machine; memory arranged as linear array
    - No stacks, no recursion.
  - Algol family
    - Stack machine, contour model of scope, heap storage
  - Smalltalk
    - Objects, communicating by messages.

Theoretical Considerations

- McCarthy's description
  - " … scheme for representing the partial recursive functions of a certain class of symbolic expressions"
- Lisp uses
  - Concept of computable (partial recursive) functions
    - Want to express *all* computable functions
  - Function expressions
    - known from lambda calculus (developed A. Church)
    - lambda calculus equivalent to Turing Machines, but provide useful syntax and computation rules

Innovations in the Design of Lisp

- Expression-oriented
  - function expressions
  - conditional expressions
  - recursive functions
- Abstract view of memory
  - Cells instead of array of numbered locations
  - Garbage collection
- Programs as data
- Higher-order functions

Parts of Speech

- Statement   load 4094 r1
  - Imperative command
  - Alters the contents of previously-accessible memory
- Expression   (x+5)/2
  - Syntactic entity that is evaluated
  - Has a value, need not change accessible memory
  - If it does, has a *side effect*
- Declaration   integer x
  - Introduces new identifier
  - May bind value to identifier, specify type, etc.

Function Expressions

- Form

  (lambda (parameters) (function_body))
- Syntax comes from lambda calculus:

  λf. λx. f (f x)

  (lambda (f) (lambda (x) (f (f x))))
- Defines a function but does not give it a name t

```
( (lambda (f) (lambda (x) (f  (f  x))))
   (lambda (x) (+ 1 x)))
)
```

Example

```
(define twice
    (lambda (f) (lambda (x) (f  (f  x))))
)

(define inc (lambda (x) (+ 1 x)))

((twice inc) 2)
⇒ 4
```

Conditional Expressions in Lisp

- Generalized if-then-else

  (cond (p_1 e_1) (p_2 e_2) … (p_n e_n))
  - Evaluate conditions p_1 … p_n left to right
  - If p_i is first condition true, then evaluate e_i
  - Value of e_i is value of expression

  No value for the expression if no p_i true, or

  p_1 … p_i false and p_{i+1} has no value, or

  relevant p_i true and e_i has no value

Conditional statements in assembler

Conditional expressions apparently new in Lisp

Examples

(cond ((< 2 1) 2) ((< 1 2) 1))

has value 1

(cond ((< 2 1) 2) ((< 3 2) 3))

has no value

(cond (*diverge* 1) (true 0))

no value, if *expression* diverge loops forever

(cond (true 0) (*diverge* 1))

has value 0

Strictness

- An operator or expression form is *strict* if it can have a value only if all operands or subexpressions have a value.
- Lisp cond is not strict, but addition is strict
  - (cond (true 1) (*diverge* 0))
  - (+ e_1 e_2)

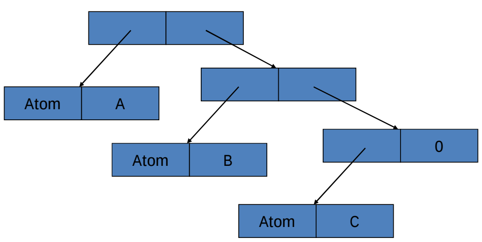
Details: (define loop (lambda (x) (loop x)))

diverge ≈ (loop ())

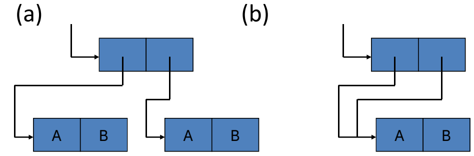
Lisp Memory Model

- Cons cells

- Atoms and lists represented by cells



Sharing



- Both structures could be printed as ((A.B) . (A.B))
- Which is result of evaluating

(cons (cons 'A 'B) (cons 'A 'B)) ?

Note: Scheme actually prints using combination of list and dotted pairs

Garbage Collection

- Garbage:

  At a given point in the execution of a program *P*, a memory location *m* is *garbage* if no continued execution of *P* from this point can access location *m*.
- Garbage Collection:
  - Detect garbage during program execution
  - GC invoked when more memory is needed
  - Decision made by run-time system, not program

This is can be very convenient. Example: in building text-formatting program, ~40% of programmer time on memory management.

Examples

(car (cons (e_1) (e_2)))

Cells created in evaluation of e_2 may be garbage, unless shared by e_1 or other parts of program

((lambda (x) (car (cons (… x…) (... x ...)))

'(Big Mess))

The car and cdr of this cons cell may point to overlapping structures.

Mark-and-Sweep Algorithm

- Assume tag bits associated with data
- Need list of heap locations named by program
- Algorithm:
  - Set all tag bits to 0.
  - Start from each location used directly in the program. Follow all links, changing tag bit to 1
  - Place all cells with tag = 0 on free list

Why Garbage Collection in Lisp?

- McCarthy's paper says this is
  - "… more convenient for the programmer than a system in which he has to keep track of and erase unwanted lists."
- Does this reasoning apply equally well to C?
- Is garbage collection "more appropriate" for Lisp than C? Why?

Programs As Data

- Programs and data have same representation
- Eval function used to evaluate contents of list
- Example: substitute x for y in z and evaluate

```
(define substitute (lambda (x y z)
    (cond   ((null z) z)
            ((atom z) (cond ((eq z y) x ) (true z)))
             (true  (cons (substitute x y (car z))
                          (substitute x y (cdr z)))))))
(define substitute-and-eval
    (lambda (x y z) (eval (substitute x y z))))
(substitute-and-eval  '3  'x  '(+ x 1))
```

Recursive Functions

- Want expression for function f such that

  (f x) = (cond ((eq x 0) 0) (true (+ x (f (- x 1)))))
- Try

  (lambda (x) (cond ((eq x 0) 0) (true (+ x (f (- x 1))))))

  but f in function body is not defined.
- McCarthy's 1960 solution was operator "label"

```
(label f
   (lambda (x) (cond ((eq x 0)  0)  (true  (+ x (f  (- x 1 )))))))
```

Recursive vs. non-recursive declarations

- Recursive definition
  - (define f

    (lambda (x) (cond ((eq x 0) 0) (true (+ x (f (- x 1)))))))
  - Legal Scheme: treats inner f as function being defined
- Non-recursive definition
  - (define x (+ x 2))
  - Error if x not previously defined

    While evaluating arguments to + in expression (+ x 2):

    Unbound variable: x

    ABORT: (misc-error)

Higher-Order Functions

- Function that either
  - takes a function as an argument
  - returns a function as a result
- Example: function composition

```
(define  compose
    (lambda (f  g)   (lambda (x)  (f  (g   x)))))
```
- Example: maplist

```
(define  maplist  (lambda (f  x)
    (cond  ((null x)   ())
           (true  (cons (f (car x))  (maplist f (cdr x )
    ))))))
```

Example

```
(define inc (lambda (x) (+ x 1)))
(maplist inc '(1 2 3))
⇒ (2 3 4)
```

Scheme preamble:

```
(define true #t)
(define false #f)
(define eq eq?)
(define null null?)
```

Efficiency and Side-Effects

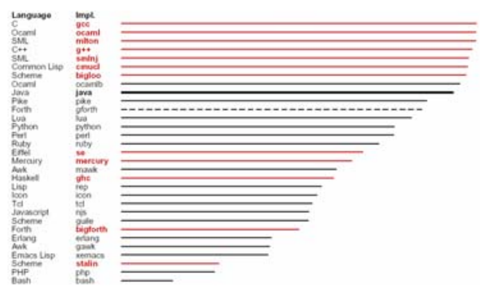
- Pure Lisp: no side effects
- Additional operations added for “efficiency”
  - (rplaca x y) replace car of cell x with y
  - (rplacd x y) replace cdr of cell x with y
- What does “efficiency” mean here?
  - Is (rplaca x y) faster than (cons y (cdr x)) ?
  - Is faster always better?

Example

```
(define p '(A B))
(rplaca p 'C)
(rplacd p 'D)
p
⇒ (C . D)
```

- Scheme preamble
  - (define rplaca set-car!)
  - (define rplacd set-cdr!)

Language speeds



www.bagley.org/~doug/shoutout*: Completely Random and Arbitrary Point System*

Summary: Contributions of Lisp

- Successful language
  - symbolic computation, experimental programming
- Specific language ideas
  - Expression-oriented: functions and recursion
  - Lists as basic data structures
  - Programs as data, with universal function `eval`
  - Stack implementation of recursion via "public pushdown list"
  - Idea of garbage collection.