## Overview

- Announcement
- Lisp Basics



## Announcement

- CMUCL is available in: `/opt/apps/cmucl/bin/lisp`
- You may use GNU Common List (GCL)
  `http://www.gnu.org/software/gcl/`
  which is available on most Linux platforms.
- There is also a commercial version of Common Lisp which is free to students:
  - Allegro Common Lisp
  - Supports Linux, windows, FreeBSD, Mac OS X
  - `http://www.franz.com/downloads`



## Outline of Writing and Running Lisp

1. Write a program (function definitions) in a file: `blah.lsp`

```
(defun mysq (x)
   (* x x)
)

(defun mytest (x)
   (if (> x 10)
       'Blah
       'Poo
   )
)
```

2. Run lisp `/opt/apps/cmucl/bin/lisp`
3. Load function definitions `(load "blah.lsp")`
4. Run functions

```
(mysq 10)
(mytest 2)
```



## LISP: A Quick Overview

- Components: Atoms, Lists, and Functions.
- Basics: list, math, etc.
- Arrays and SETQ vs. SETF
- Variable binding
- Lexical vs. dynamic scope
- Conditionals, predicates, iterations, etc.
- User-defined function
- Recursion
- Output

## Components

Symbolic expression = ATOM or LIST.

- Atom: numbers, variable names, etc.
  [<letters>|<digits>]+
  e.g.: 1, 10, foo, bar, this-is-an-atom
- List: functions, list of items
  "(" [<list>|<atom>]* ")"
  e.g.: (a), (1 (1 2 3) (4 5 6))
- NIL: it is an atom and at the same time a list.
  NIL is the same as ()
- T: true, as opposed to NIL.
  See conditionals and predicates.



## Basics

- quote: returns a literal (i.e. not evaluated) atom or a list.
  '(+ 2 3) → (+ 2 3)
  (quote (+ 2 3)) → (+ 2 3)
  Compare with:
  (+ 2 3) → 5
  (eval '(+ 2 3)) → 5
- Basically, you can think of a quoted atom or list as **data**, as opposed to instruction, in Lisp.



## Evaluation in Lisp

- Lisp basically tries to **evaluate** everything (atom or a list) that is not quoted.
- If it sees an **atom**, it treats it as a **variable**, and tries to find out a value assigned to it.
- If it sees a **list**, it treats it as a **function**, where the first element in the list is seen as the **function name** and the rest **function arguments**.
- The quote function is used to exactly **avoid** such behavior (i.e., evaluate by default).



## Evaluation in Lisp (cont'd)

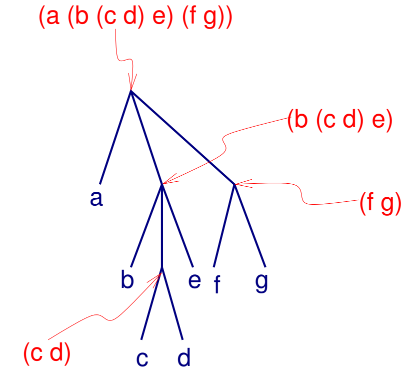
- For example, if you typed in (hello (my world)),
  1. Lisp will see the first entry in that list as a function and tries to evaluate it using the argument (my world).
  2. But, it needs to evaluate all of the arguments first, so it will try to evaluate (my world).
  3. Since this also looks like a function, Lisp will now try to evaluate function my.
  4. To do that, it needs to evaluate the symbol world. Since it is an atom, Lisp will check if any value is assigned to the symbol world (i.e., treating it as a variable).
- What about ((hello world) (my friend)) ?

## Evaluation in Lisp (cont'd)

- What about `(* 10 b)` ?
- Lisp sees a well-defined function `*` and proceeds to evaluate its arguments first.
- It is happy with the number `10`, so it proceeds on to evaluate `b`.
- Here's where the problem begins. If you already did something like `(setq b 20)`, then Lisp knows `b` can be evaluated to the value `20`, so it will do that and evaluate `*` with that and return `200`.
- If you haven't defined `b`, Lisp will treat it as an unbound variable, and balk.
- What about `(* 10 'a)`?



## List




- List can be seen as trees: atoms at leaves and internal nodes representing lists.
- Once this is understood, the list operations such as `car`, `cdr`, `cons` become easy to understand.
- Exercise: draw the tree for `(((((((a)))))))`



## Basics: List

- `car`: returns first element (atom or list)
  `(car '(a (b c)))` → `A`
  `(car '((b c) a))` → `(B C)`
- `cdr`: returns all except the first element of a list, as a list
  `(cdr '(a (b c)))` → `((B C))`
  `(cdr '((b c) a))` → `(A)`



## Basics: List

- Combinations are possible: `cXXXXr` where X=(a|d)
  `(cadr '(a (b c))) == (car (cdr '(a (b c))))` → `(B C)`
- `list`: creates a list out of atoms and lists
  `(list 'a '(1 2) '((3 5) (7 8)))`
  → `(A (1 2) ((3 5) (7 8)))`
- `length`: number of elements in a list `(length '(a b c))` → `3`
- Some shorthands: `first, second, third, ..., nth, rest`
  `(first '(a b))` → `A`
  `(nth 2 '(a b c d))` → `B`

## Basics: List

- `CONS`: append an atom (or a list) and a list

  `(cons 'a '(1 2 3)) -> (A 1 2 3)`

  `(cons '(a) '(1 2 3)) -> ((A) 1 2 3)`

- `APPEND`: append two lists

  `(append '(1 2) '(4 5)) -> (1 2 4 5)`



## Basics: Assignments/Arrays

- `setq`: assignment of value to a **symbol**

  `(setq x 10)` → `10`

  `x` → `10`

- `setf`: can set the value of a symbol (== setq) or **location or structure** (next slide).

## Arrays and SETQ vs. SETF

- `make-array` : create an array
- `aref` : array reference
- `setf` : set value of array element



## Arrays and SETQ vs. SETF

Note: * is the Lisp prompt.

```
* (setq a (make-array '(3 3)))
#2A((NIL NIL NIL) (NIL NIL NIL) (NIL NIL NIL))
* (aref a 2 2)
NIL
* (setf (aref a 2 2) 1000)
1000
* a
#2A((NIL NIL NIL) (NIL NIL NIL) (NIL NIL 1000))
* (setq (aref a 2 2) 1000)
Error: (AREF A 2 ...) is not a symbol.
...
```



## More Fun with SETF

Replace list element with `SETF`. Note: `SETQ` will not work!

```
*(setf b '(1 (2 3) 4))
(1 (2 3) 4)

*(caadr b)
2

*(setf (caadr b) 'abcdefg)
ABCDEFG

*b
(1 (ABCDEFG 3) 4)
```

## Basics: Math

- `(+ 1 2) (* 3 4) (+ (* 2 3) (/ 4 5))` etc.
- `(max 1 2 3 4 5) (min 4 6 5)`
- `(sqrt 16) (expt 2 3) (round 3.141592)`

## Basics: File Loading

- `(load "filename")`



## Function

- `defun` : user defined function

```
* (defun mult (x y) (* x y) )
DEFUN
* (mult 10 20)
200
```

- Use the `let` and `let*` forms:

```
(defun mult (x y)
    (let ((tx x) (ty y))
        (* tx ty)
    )
)
```



## Recursion

- Fibonacci number:

  F(N) = F(N-1) + F(N-2), F(1)=1, F(2)=2.

```
(defun fibo (x)
  (cond
     ((equal x 1) 1)
     ((equal x 2) 2)
     ((> x 2)
          (+ (fibo (- x 1)) (fibo (- x 2))))
  )
)
*(fibo 4)
5
*(fibo 5)
8
```



## Binding

You can bind variables anywhere in a program with the `let` or `let*` special forms to create a local context.

- `let` and `let*` : lexical scope (local context)

```
(let (local var list) BODY)
(let ((x 10) y (z 20)) BODY)
(let* ((x 10) (y (* 2 x)) z)) BODY)
```

- Either just a variable or (variable default-value).
- With `let*`, values from previous vars can be used to define new value.

```
(let* ((x 10) (y (* 2 x)) z)) BODY)
```

## Use of Local Scope

- Always use `(let ... )` or `(let* ...)` be your **first (and only) statement** in your function, if you are writing something complex which is not like a mathematical function in its usual sense.
- Think of it as declaring local variables in C/C++.

```
(defun func-name (arg1 arg2)
   (let (localx localy localz)
        (expression1  args)
        (expression2  args)
        (expression3  args)
        (expression4  args)
        (expression5  args)
   )
)
```



## Binding: Example

```
* (let ((a 3)) (+ a 1))
4
* (let ((a 2)
        (b 3)
        (c 0))
    (setq c (+ a b))
    c)
5
* (setq c 4)
4
* (let ((c 5)) c)
5
* c
4
```



## Lexical Scope

Return value according to the lexical scope where it was **defined**.

```
* (setq regular 5)
5
* (defun check-regular () regular)
CHECK-REGULAR
* (check-regular)
5
* (let ((regular 6)) (check-regular))
5
```



## Dynamic Scope

Use the `defvar` to define a special variable that is dynamically scoped. (Just think of it as defining a global variable.)

```
* (defvar *special* 5)
*SPECIAL*
* (defun check-special () *special*)
CHECK-SPECIAL
* (check-special)
5
* (let ((*special* 6)) (check-special))
6
* *special*
5
*(let ((x 23)) (check-special))
5
```

## Group (or Block) of Commands

`progn` returns the result of the last element, but evaluates all s-expressions in the argument list.

- `(progn (setq a 123) (* 5 10))` $\longrightarrow$ `50`
  `a` $\longrightarrow$ `123`

A better way of writing it is:

```
(progn
      (setq a 123)
      (* 5 10)
)
```



## How Not to Define a Block

A common **mistake** is to define a block using just bare parentheses, instead of using the function `(progn ...)`:

```
(
    (setq x 10)
    (setq y 20)
    (* x y)
)
```

It looks fine, but as mentioned earlier, Lisp will interpret this list as a function that has a name `(setq x 10)` and two argument `(setq y 20)` and `(* x y)`. So, **don't do this!**



## Conditionals: the Ps.

**p** is for **p**redicate:

- `numberp, listp, symbolp, zerop, ...`
- common comparisons: $<$, $>$,
- `equal` : if the values are the same.
- `eq` : if the memory locations are the same.
- `and, or, not` : logical operators.

Returns either `NIL` or `T`.



## Control Flow

```
IF STATEMENT
(if (> 2 3)  ; condition
      (+ 4 5) ; when true
      (* 4 5) ; when false
)

SWITCH STATEMENT
(cond ((testp1) (return-value1))  ; condition 1
      ((testp2) (return-value2))  ; condition 2
      ((testp3) (return-value3))  ; condition 3
      (t (default-value))   ; default
)
```

## Iterations

```
DOTIMES
(dotimes (index-var upper-bound result-var) BODY)

* (dotimes (k 1 val) (setq val k))
0

* (dotimes (k 10 val) (setq val k))
9
```

Also find out more about `dolist`, `do`, and `loop`.



## Output

- `print` : print a string
  `(print "hello")`
- `format` : format a string; `(format dest string args)`
  dest: determines what to return – t: return NIL, NIL: return string.

```
~% : insert CR
~S : S-expression
~A : ascii
~D : integer
~widthD : blank space e.g. ~5D
~F : floating point
~width,decimalF : width and decimal point
```



## Format: examples

```
* (format t "Hello, world!")
Hello, world!
NIL

* (format nil "Hello, world!")
"Hello, world!"
```



## Format: examples

```
* (format
      nil
      "The list is ~s and~%the text is ~a"
      (list 'a 'b 'c)
      "This is a string"
  )
"The list is (A B C) and
the text is This is a string"
```

## Format: examples

```
* (format
      nil
      "One: ~d~%Two:~f~%Three:~5,2f"
       12 (/ 4 3) (/ 4 3)
   )
"One: 12
Two:1.3333334
Three: 1.33"
```



## Dealing with Errors

```
* a <--- errorneous input

Error in KERNEL::UNBOUND-SYMBOL-ERROR-HANDLER:  the varia

Restarts:
  0: [ABORT] Return to Top-Level.

Debug  (type H for help)

(EVAL A)
Source: Error finding source:
Error in function DEBUG::GET-FILE-TOP-LEVEL-FORM:  Source
  target:code/eval.lisp.
0] q <--- go back to top level

*
```



## Overview

- Some more LISP stuff: user input, trace, more setf, etc.
- Symbolic Differentiation:
  [$q$] does it need intelligence?
- Expression Simplification



## READ: User Input

`READ`: keyboard input from user

```
*(read)
hello
HELLO

*(if (equal (read) 'hello)
         'good
         'bad
)
hello
GOOD
```

## TRACE/UNTRACE: call tracing

```
*(trace fibo)
(FIBO)
*(fibo 4)
  1> (FIBO 4)
    2> (FIBO 3)
      3> (FIBO 2)
      <3 (FIBO 2)
      3> (FIBO 1)
      <3 (FIBO 1)
    <2 (FIBO 3)
    2> (FIBO 2)
    <2 (FIBO 2)
  <1 (FIBO 5)
5
*
```



## Symbolic Differentiation

Original concept and code borrowed from Gordon Novak's AI course at UTCS.



## Symbolic Differentiation

Basics: given variable $x$, functions $f(x), g(x)$, and constant (i.e. number) $a$:

1. $$\frac{da}{dx} = 0, \frac{d(a \times x)}{dx} = a$$
2. $$\frac{d(f+g)}{dx} = \frac{df}{dx} + \frac{dg}{dx}$$
3. $$\frac{d(f \times g)}{dx} = \frac{df}{dx} \times g + f \times \frac{dg}{dx}$$

The operators can be extended to: binary minus (e.g. `(- x 1)`), unary minus (e.g. `(- x)`), division (e.g. `(/ x 10)`, etc.



## Describing in LISP (I)

`(deriv <expression> <variable>)`

1. $$\frac{da}{dx} = 0, \frac{d(a \times x)}{dx} = a$$

```
(deriv '10 'x) -> 0
(deriv '(* 10 x) 'x) -> 10
```

## Describing in LISP (II)

```
(deriv <expression> <variable>)
```

1.
$$\frac{d(f+g)}{dx} = \frac{df}{dx} + \frac{dg}{dx}$$

```
(deriv '(+ (* x 10) (+ 25 x)) 'x)
== (list
        '+
        (deriv '(* x 10) 'x)
        (deriv '(+ 25 x) 'x)
    )
```



## Describing in LISP (III)

```
(deriv <expression> <variable>)
```

1.
$$\frac{d(f\times g)}{dx} = \frac{df}{dx}\times g + f\times\frac{dg}{dx}$$

```
(deriv '(* (+ 14 x) (* x 17)) 'x)
==(list
     '+
     (list '* (deriv '(* 14 x) 'x) '(* x 17))
     (list '* '(+ 14 x) (deriv '(* x 17) 'x))
  )
```



## DERIV: the core function

Pseudo code (basically a recursion):

```
(defun deriv (expression var) BODY)
```

1. if `expression` is the same as `var` return 1
2. if `expression` is a number return 0
3. if `(first expression)` is `'+`, return
   ```
   '(+ (deriv (second expression) var)
       (deriv (third expression) var)
   ```
4. and so on.



## Main Function: DERIV

You can make separate functions for each operator:

```
(defun deriv (expr var)
  (if (atom expr)
    (if (equal expr var) 1 0)
    (cond
        ((eq '+ (first expr))     ; PLUS
            (derivplus expr var))
        ((eq '* (first expr))     ; MULT
            (derivmult expr var))
        (t    ; Invalid
            (error "Invalid Expression!"))
     )
   )
)
```

## Calling DERIV from DERIVPLUS

Then, you can call deriv from derivplus, etc.

```
(defun derivplus (expr var)
    (list '+
          (deriv (second expr) var)
          (deriv (third expr) var)
    )
)
```



## Expression Simplification

Problem: a lot of nested expression containing

(* 1 x) (* x 1) (+ 0 x) (+ x 0) (+ 3 4) ...

which are just x, x, x, x, and 7.

Use simplification rules:

1. (+ <number> <number>) : return the evaluated value
2. (* <number> <number>) : return the evaluated value
3. (+ 0 <expr>) (+ <expr> 0) : return <expr>
4. (* 1 <expr>) (* <expr> 1) : return <expr>
5. (- (- <expr>)) : return <expr>

HINT: look at the raw result and see what can be reduced.



## SPLUS: Simplify (+ x y)

```
(defun splus (x y)
    (if (numberp x)
        (if (numberp y)
            (+ x y)
            (if (zerop x)
                y
                (list '+ x y)
            )
        )
        (if (and (numberp y) (zerop y))
            x
            (list '+ x y)
        )
    )
)
```



## Programming Assignment #1

- Symbolic differentiation: details TBA.