Overview

- Announcement
- Lisp Basics

Announcement

- CMUCL will be made available on CSCE Linux machines.
  - You can also download a binary release for local use: `https://www.cons.org/cmucl/download.html`: Just download, untar and you can run it as is.
  - Debian package: `http://packages.debian.org/cmucl`
  - Redhat package: `https://admin.fedoraproject.org/pkgdb/acls/name/cmucl`
- 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`

Installing CMUCL binary

- Go to `https://www.cons.org/cmucl/download.html`
- Download Non-Unicode version 20d for your OS.
  - Example: for Linux it is `http://common-lisp.net/project/cmucl/downloads/release/20d/cmucl-20d-non-unicode-x86-linux.tar.bz2`
- Login to your CSE linux host.

```
mkdir cmucl
cd cmucl
tar -xjvf [PATH-TO-]/cmucl-20d-non-unicode-x86-linux.tar.bz2
./bin/lisp
```


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`
   - Note: this can be different depending on where the binary is.
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)

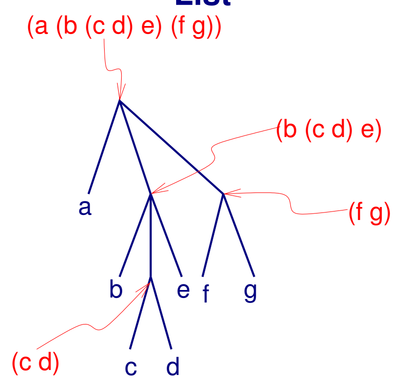
- For example, if you typed in `(hello (my world))`,
  1. Lisp will see the first entry in that list as a function and tries to evaluate it using the argument `(my world)`.
  2. But, it needs to evaluate all of the arguments first, so it will try to evaluate `(my world)`.
  3. Since this also looks like 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)`?

What about `(setq b 20)` itself?? – more discussion later.

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

- `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).

Basics: Special Forms

`setq` and a small set of forms that are known as *special forms* do not follow the standard argument evaluation rule!! That is, the first argument `x` is not evaluated!

`if, let, func, progn, setq, quote, ...` are all special forms.

See `https://www.cs.cmu.edu/Groups/AI/html/cltl/clm/node59.html` for details.

Basics: Assignments/Arrays

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))` → `50`
  `a` → `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

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.

Inspired by Gordon Novak's course at UT Austin.

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 Exercise

- Symbolic differentiation: details TBA.
- This is an exercise, and will not be graded.
- Completing this exercise will help you with the first two programming assignments.