

## Overview

- Announcement
- Lisp Basics

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## Outline of Writing and Running Lisp

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

```
(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.lisp"`)
4. Run functions  
`(mysq 10)`  
`(mytest 2)`

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## 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`

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## 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

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## 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.

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## 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).

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## 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.

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## 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))` ?

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## 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)` ?

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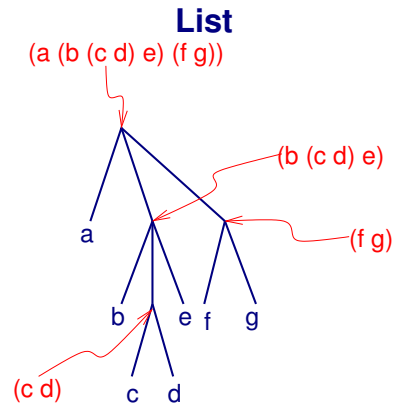
## Basics: List

- `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)
```

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- 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))))))`

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## 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
```

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## 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)`

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## 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.
...
```

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## 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

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## 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)
ABCDEF

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

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## 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")`

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## 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
```

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## 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)
  )
)
```

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## 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)
```

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## 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 locally localz)
    (expression1 args)
    (expression2 args)
    (expression3 args)
    (expression4 args)
    (expression5 args)
  )
)
```

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## 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
```

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## 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
```

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## 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
```

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## 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)
)
```

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## 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`.

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## 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 arguments `(setq y 20)` and `(* x y)`. So, **don't do this!**

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## 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
)
```

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## 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`.

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## Format: examples

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

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

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## 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

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## 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"
```

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## Format: examples

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

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## Overview

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

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## Dealing with Errors

```
* a <--- erroneous 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
```

```
*
```

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## READ: User Input

```
READ: keyboard input from user
```

```
*(read)
```

```
hello
```

```
HELLO
```

```
*(if (equal (read) 'hello)
```

```
      'good
```

```
      'bad
```

```
)
```

```
hello
```

```
GOOD
```

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## 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)
```

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\*

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## Symbolic Differentiation

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

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## 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.

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## 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
```

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## 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)
  )
```

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## 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.

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## 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))
  )
```

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## 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!")))
  )
)
```

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## 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)
  )
)
```

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## 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)
      )
  )
)
```

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## 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.

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## Programming Assignment #1

- Symbolic differentiation: details TBA.

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