

# About Lisp

## *...or Lambda, the ultimate lecture*

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# Abstract

First we shall introduce symbolic, conditional and meta expressions and their recursive definitions with the  $\lambda$ -notation. Then we will briefly describe how such expressions might be represented by a computer. We shall introduce the Lisp REPL and use it to explore a number of basic Lisp paradigms such as closures, functional programming and Lisp macros. Finally we shall look at the past and present of Lisp as a language.

# What is Lisp?

What is Lisp? What can we say generally about Lisp?

- *“Lisp is a programmable programming language”<sup>(a)</sup>*
- There are many Lisps, standardised and not.
- Lisp has very little syntax.
- Lisp’s roots are in the mathematical representation of recursive functions [2].

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<sup>(a)</sup>John Foderaro, CACM, September 1991

# Conditional Expressions

$$(p_1 \rightarrow e_1, \dots, p_n \rightarrow e_n)$$

It may be read, “if  $p_1$  then  $e_1$  otherwise if  $p_2$  then  $e_2, \dots$ , otherwise if  $p_n$  then  $e_n$ ” where the  $p$ 's are propositional expressions and the  $e$ 's are expressions of any kind.

$$(1 < 2 \rightarrow 4, 1 > 2 \rightarrow 3) = 4$$

$$(2 < 1 \rightarrow 4, T \rightarrow 3) = 3$$

$(2 < 1 \rightarrow 3, 4 < 1 \rightarrow 4)$  is undefined

$$|x| = (x < 0 \rightarrow -x, T \rightarrow x)$$

# Recursive Function Definitions

$$n! = (n = 0 \rightarrow 1, T \rightarrow n \cdot (n - 1)!)$$

$$\text{sqrt}(a, x, \epsilon) = \left( |x^2 - a| < \epsilon \rightarrow x, T \rightarrow \text{sqrt}\left(a, \frac{1}{2}\left(x + \frac{a}{x}\right), \epsilon\right) \right)$$

# Church's $\lambda$ -notation

Church's  $\lambda$ -notation [2] helps distinguish between a function and a form. The expression  $y^2 + x$  is a form. A form is converted to a function once the correspondence between variables occurring the form and an ordered list of arguments is determined.

# Church's $\lambda$ -notation II

If  $\varepsilon$  is a form in variables  $x_1, \dots, x_n$  then  $\lambda((x_1, \dots, x_n), \varepsilon)$  will be taken to be the function of  $n$  variables whose value is determined by substituting the arguments for the variables  $x_1, \dots, x_n$  in that order in  $\varepsilon$  and evaluating the resulting expression.

$$\lambda((x, y), y^2 + x)(3, 4) = 19$$

The concept of a *label* is used to define recursive functions.

$$\text{label}(a, \varepsilon)$$

$$\text{label}(\text{fact}, \lambda((n), (n = 0 \rightarrow 1, T \rightarrow n \cdot (\text{fact}(n - 1))))))$$

# Symbolic Expressions

- S-expressions are formed out of:
    - (
    - )
    - .
    - infinite set of atomic symbols
1. Atomic symbols are S-expressions
  2. if  $e_1$  and  $e_2$  are S-expressions, so is  $(e_1 \cdot e_2)$

# Symbolic Expressions II

A list of arbitrary length written as

$$(m_1, m_2, \dots, m_n)$$

is represented by the S-expression

$$(m_1 \cdot (m_2 \cdot (\dots (m_n \cdot NIL) \dots)))$$

# Meta Expressions

Since we cannot describe S-expressions using S-expressions, we use M-expressions to describe primitive functions.

$$\mathit{cons}[A; B] = (A \cdot B)$$

$$\mathit{cons}[\mathit{cons}[A; B]; C] = ((A \cdot B) \cdot C)$$

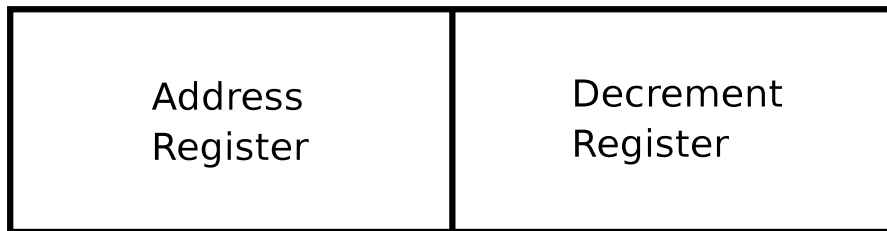
if  $x$  and  $y$  represent any two S-expressions, the following identities are true:

$$\mathit{car}[\mathit{cons}[x; y]] = x$$

$$\mathit{cdr}[\mathit{cons}[x; y]] = y$$

# Representation of List Structure: Cells

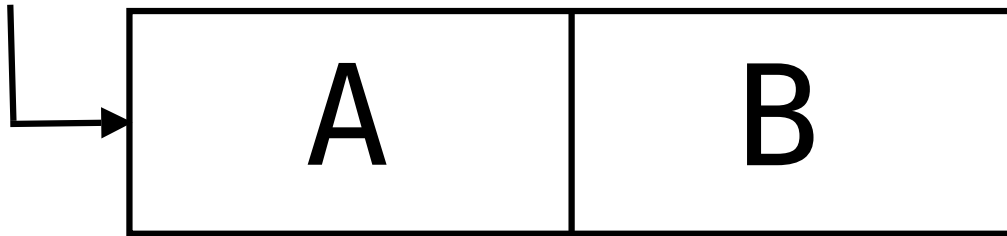
Lisp lists are typically represented using pointers to pairs of units (aka cells) of memory. The exact representation varies throughout architectures.



The first half of the cell is called the *contents of the address register* or *CAR*. The second half of the cell is called the *contents of the decrement register* or *CDR*.<sup>[4]</sup>

# Representation of List Structure: Cons

The S-expression  $(A \cdot B)$  is represented as a cons-cell whose *CAR* is the atomic symbol  $A$  and whose *CDR* is the atomic symbol  $B$ .



# Representation of List Structure: Lists

The S-expression  $(A B C)$  is represented as a chain of cells. The *CAR* of the first cell contains the atomic symbol  $A$ , the *CDR* contains a pointer to the *CAR* of the next cell, which contains the atomic symbol  $B$  and so on... Finally, the list is terminated by the atomic symbol  $NIL$  in the *CDR* of the last cell.



# The REPL and Quotation

The *read-eval-print loop* or REPL, is the heart of an interactive Lisp environment. The REPL evaluates S-expressions and returns the result, which is also an S-expression.

```
CL-USER> (list 1 2 3 4)
```

```
=> (1 2 3 4)
```

```
CL-USER> '(list 1 2 3 4)
```

```
=> (LIST 1 2 3 4)
```

```
CL-USER> (cons '+ (list 1 2))
```

```
=> (+ 1 2)
```

```
CL-USER> (+ 1 2)
```

```
=> 3
```

```
CL-USER> 3
```

```
=> 3
```

# $\lambda$ -notation and Lisp

$label (fact, \lambda ((n), (n = 0 \rightarrow 1, T \rightarrow n \cdot (fact (n - 1))))))$

```
CL-USER> (defun fact (n)
           ((lambda (x)
              (cond ((= x 0) 1)
                    (t (* x (fact (- x 1))))))
            n))
```

```
CL-USER> (fact 5)
=> 120
```

# Closures

A combination of a function and a set of variable bindings<sup>(a)</sup> is called a closure[5].

```
CL-USER> (let ((n 0))
           (defun serial ()
             (cons (random 1000)
                   (incf n))))
```

```
CL-USER> (serial)
=> (715 . 1)
```

```
CL-USER> (serial)
=> (582 . 2)
```

...

---

<sup>(a)</sup>For why this is problematic, see [9]

# Functions as arguments

The function:

```
(defun sum-cubes (a b)
  (if (> a b)
      0
      (+ (cube a)
          (sum-cubes (+ a 1) b))))
```

...is just a special case of:

$$\sum_{n=a}^b f(n) = f(a) + \dots + f(b)$$

...where:

$$f(n) = n^3$$

[1]

# Functions as arguments II

```
(defun sum (term a next b)
  (if (> a b)
      0
      (+ (funcall term a)
          (sum term (funcall next a) next b))))
```

```
(defun cube (n) (* n n n))
```

```
(defun sum-cubes (a b)
  (sum #'cube a #'1+ b))
```

```
CL-USER> (sum-cubes 1 10)
=> 3025
```

[1]

# Functions as return values

If  $Dg(x)$  is the derivative of  $g$  evaluated at  $x$ :

$$Dg(x) = \frac{g(x + dx) - g(x)}{dx}$$

...then we can express the idea as:

```
CL-USER> (let ((dx 0.001))
           (defun deriv (g)
             (lambda (x)
               (/ (- (funcall g (+ x dx))
                    (funcall g x))
                 dx))))
```

[1]

# Functions as return values II

So given:

```
(defun square (n) (* n n))
```

```
(defun cube (n) (* n n n))
```

```
(defun identity (n) n)
```

...we get:

```
CL-USER> (funcall (deriv #'cube) 5)  
=> 75.01221
```

```
CL-USER> (funcall (deriv #'square) 5)  
=> 10.000229
```

```
CL-USER> (funcall (deriv #'identity) 5)  
=> 0.99992746
```

# Lisp Macros

- Transform one form into another
- Transform form first, eval or compile after
- Controls evaluation of expressions

# Lisp Macros: arithmetic-if

```
(defmacro arithmetic-if (test ngf zrf psf)
  (let ((var (gensym)))
    `(let ((,var ,test))
      (cond ((< ,var 0) ,ngf)
            ((= ,var 0) ,zrf)
            (t ,psf))))))
```

[8]

# Lisp Macros: arithmetic-if II

```
CL-USER> (let ((x 2))
           (arithmetic-if (- x 4.0)
                          (- x)
                          (error "Strange zero")
                          x))

=> -2
```

```
CL-USER> (let ((n -20))
           (arithmetic-if (* n n n)
                          (format t "Haifux!")
                          99
                          (+ n 0.5)))

=> Haifux!
```

# Lisp Macros: arithmetic-if III

```
CL-USER> (macroexpand
           '(arithmetic-if (* n n n)
                          (format t "Haifux!")
                          99
                          (+ n 0.5)))
```

```
=> (LET ((#:G1208 (* N N N)))
     (COND ((< #:G1208 0) (FORMAT T "Haifux!"))
           ((= #:G1208 0) 99)
           (T (+ N 0.5))))
```

# Lisp History

A short and non-conclusive chronology of Lisp [6]. If this part seems a bit lengthy, it is because Lisp is very old!

- 1956 — Early thoughts
- 1958 — First implementation
- 1960-1965 — Lisp 1.5 (on an IBM 7094) and Lisps on the PDP-1 ,PDP-6, PDP-10

All Lisps were still basically identical until 1965. The PDP-6 and PDP-10 were well suited for Lisp with 36-bit words, 18-bit addresses and half-word instructions. [7]

# Lisp History II

- *1960's until the early 1980's* — MacLisp<sup>(a)</sup> on the PDP-10 and Honeywell 6180 (under Multics)

MacLisp would later become Zetalisp on the Lisp-Machine and Scheme. MacLisp had numeric functions on par with the FORTRAN of the time. <sup>(b)</sup> This was a “high-water mark” to be revisited only recently.

The MacLisp community was very “open source” in spirit.

- *Same era as MacLisp* — Interlisp on PDP-10's, Vaxen and specialised XEROX Lisp machines.

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<sup>(a)</sup>Mac == MIT's Project MAC, started 1963

<sup>(b)</sup>Fateman, Richard J. in a reply to editorial ACM SIGSAM Bulletin 25, pp. 9-11

March 1973

# Lisp History III

- 1975 — Scheme, the Actor model of computation (now called “continuations” in Scheme), lexical scoping and closures
- *mid 1970's* — Lisp360 and Lisp370 (later called Lisp/VM) on the IBM 360 and IBM 370
- 1974-1978 — MIT Lisp machines: CONS, CADR, LMI inc. and the Symbolics 3600
- 1973-1980 — Xerox Lisp machines, the Alto<sup>(a)</sup> and the “D-machines”: Dorado, Dolphin and Dandelion

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<sup>(a)</sup>The Alto was used to build the first Smalltalk environment.

# Lisp History IV

- *Early 1980's* — Franz Lisp<sup>(a)</sup> for UNIX
- *1981* — Emacs Lisp inside GNU/Emacs under UNIX
- *1982* — T under UNIX and VMS
- *1984* — CLtL I: Common Lisp by Steele, Fahlman, Moon, Weinreb and Gabriel
- *1986* — X3J13: Common Lisp ANSI standard

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<sup>(a)</sup>Franz Inc. still exist today

# Lisp Present: Scheme

- Created by Gerald Jay Sussman and Guy Steele
- Inspired by the *Actors* model of computation
- Minimalistic<sup>(a)</sup>
- Standard, but still being standardised (IEEE, R6RS, ANSI etc.)
- Inexplicably... GNU/Guile

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<sup>(a)</sup>The complete Scheme standard is smaller than the index of CLtL2

# Lisp Present: Common Lisp

- Created by the Common Lisp standards group
- The canonical language for modern Lisp applications
- Bignums, complex numbers, extendable arithmetic (no infix)
- Optional strict typing, assertions and fast, optimising compilers
- Built-in arrays, vectors, hash-tables and other data structures
- Object System (CLOS)
- Interactive environment<sup>(a)</sup>

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<sup>(a)</sup>Here “interactive” is meant in the sense that the working system can be inspected and changed during its operation.

# Lisp Present: Emacs Lisp

- Created by Richard M. Stallman
- Largely inspired by MacLisp
- Indefinite scope
- VM-like with the GNU/Emacs core as OS binding

# Notable omissions

- Compilers
- CLOS
- Advanced macros
- Scheme continuations

# Bouquets and Brickbats

Greenspun's Tenth Rule of Programming: any sufficiently complicated C or Fortran program contains an ad hoc informally-specified bug-ridden slow implementation of half of Common Lisp.

– Philip Greenspun

Lisp is a beautiful language, but all the programs written in Lisp turn out horribly ugly.

– Larry Wall, OSDC.org.il 2006 (paraphrased)

# Bouquets and Brickbats II

The greatest single programming language ever designed

- Alan Kay (designer of the Smalltalk language), On Lisp

Plenty of brilliant programmers know lisp just fine and still choose other languages. Most of them, in fact.

- Joel Spolsky, Fogcreek software

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