INF4820: Algorithms for Artificial Intelligence and Natural Language Processing

Common Lisp Fundamentals

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Last Week: What is AI?

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$\rightarrow$ Toolkit of ('clever') methods for representation and problem solving.

Lisp

Why Common Lisp?

Eric S. Raymond (2001), *How to Become a Hacker*:

Lisp is worth learning for the profound enlightenment experience you will have when you finally get it; that experience will make you a better programmer for the rest of your days, even if you never actually use Lisp itself a lot.

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Lisp is worth learning for the profound enlightenment experience you will have when you finally get it; that experience will make you a better programmer for the rest of your days, even if you never actually use Lisp itself a lot.

- High-level and efficient language with especially strong support for symbolic and functional programming.
- Rich language: multitude of built-in data types and operations.
- Easy to learn:
  - extremely simple syntax,
  - straightforward semantics.
- ANSI-standardized and stable.
- Incremental and interactive development.

Lisp

- Conceived in the late 1950s by John McCarthy—one of the founding fathers of AI.
- Originally intended as a mathematical formalism.
- A family of high-level languages.
- Several dialects, e.g. Scheme, Clojure, Emacs Lisp, and Common Lisp.
- Although a multi-paradigm language, functional style prevalent.

Basic Common Lisp in a Couple of Minutes

- Testing a few expressions at the REPL;
- the read–eval–print loop.
- (= the interactive Lisp-environment)
- '?' represents the REPL prompt and '$\rightarrow$' what an expression evaluates to.

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Examples

```
? "this is a string"
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? 42
→ 42
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Examples

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? 42
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? t
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? nil
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Examples

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? 42
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? t
→ t

? nil
→ nil

? pi
→ 3.1415926535897d0
```

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Examples

```
? "this is a string"
→ "this is a string"

? 42
→ 42

? t
→ t

? nil
→ nil

? pi
→ 3.1415926535897930

? foo
→ error; unbound
```

A Note on Terminology

- Lisp manipulates so-called *symbolic expressions*.
- AKA s-expressions or sexps.
- Two fundamental types of sexps;
  1. atoms (e.g., `nil`, `t`, numbers, strings, symbols)
  2. lists containing other sexps.
- Sexps are used to represent *both* data and code.

Function Calls

- "Parenthesized prefix notation"
- First element (prefix) = operator (i.e. the procedure or function).
- The rest of the list is the operands (i.e. the arguments or parameters).
- Use nesting (of lists) to build compound expressions.
- Expressions can span multiple lines; indentation for readability.

Examples

```
? (+ 1 2)
→ 3
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? (+ 1 2 10 7 5)
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? (/ (+ 10 20) 2)
→ 15
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Examples

```
? (+ 1 2)
→ 3

? (+ 1 2 10 7 5)
→ 25

? (/ (+ 10 20) 2)
→ 15

? (* (+ 42 58)
     (- (/ 8 2) 2))
→ 200
```

The Syntax and Semantics of CL

```
? (expt (- 8 4) 2)
→ 16
```

- You now know (almost) all there is to know about (the rules of) CL.

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- You now know (almost) all there is to know about (the rules of) CL.
- The first element of a list names a function that is invoked with the values of all remaining elements as its arguments.
- A few exceptions, called special forms, with their own evaluation rules.

Creating our own functions

- The special form `defun` associates a function definition with a symbol:

General form

(`defun` *name* (*parameter*$_1$ ... *parameter*$_n$) *body*)

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Example

```
? (defun average (x y)
    (/ (+ x y) 2))
```

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Example

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    (/ (+ x y) 2))

? (average 10 20)
→15
```

The ‘Hello World!’ of Functional Programming

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(defun !  (n)
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      (* n (!  (- n 1)))))
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The 'Hello World!' of Functional Programming

- Classic example: the factorial function.
- A recursive procedure; calls itself, directly or indirectly.
- May seem circular, but is well-defined as long as there's a base case terminating the recursion.
- For comparison: a non-recursive implementation (in Python).

$$n! = \begin{cases} 1 & \text{if } n = 0 \\ n \times (n-1)! & \text{if } n > 0 \end{cases}$$

```
(defun !  (n)
  (if (= n 0)
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      (* n (!  (- n 1)))))
```

```
def fac(n):
    r = 1
    while (n > 0):
        r = r * n
        n = n - 1
    return r
```

A Special Case of Recursion: Tail Recursion

- A more efficient way to define $n!$ recursively.
- Use a helper procedure with an accumulator variable to collect the product along the way.

```
(defun ! (n)
  (!-aux 1 1 n))

(defun !-aux (r i n)
  (if (> i n)
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      (!-aux (* i r)
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- Most CL compilers do *tail call optimization* (TCO), so that the recursion is executed as an iterative loop.
- (The next lecture will cover CL's built-in `loop` construct.)

Tracing the processes

Recursive

```
(defun ! (n)
  (if (= n 0)
      1
      (* n (! (- n 1)))))
```

```
? (! 7)
⇒ (* 7 (! 6))
⇒ (* 7 (* 6 (! 5)))
⇒ (* 7 (* 6 (* 5 (! 4))))
⇒ (* 7 (* 6 (* 5 (* 4 (! 3)))))
⇒ (* 7 (* 6 (* 5 (* 4 (* 3 (! 2))))))
⇒ (* 7 (* 6 (* 5 (* 4 (* 3 (* 2 (! 1)))))))
⇒ (* 7 (* 6 (* 5 (* 4 (* 3 (* 2 1))))))
⇒ (* 7 (* 6 (* 5 (* 4 (* 3 2)))))
⇒ (* 7 (* 6 (* 5 (* 4 6))))
⇒ (* 7 (* 6 (* 5 24)))
⇒ (* 7 (* 6 120))
⇒ (* 7 720)
→ 5040
```

Tail-Recursive

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(defun ! (n)
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⇒ (!-aux 720 7 7)
⇒ (!-aux 5040 8 7)
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? (* 2 pi) → 6.283185307179586d0
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? '(* 2 pi) → (* 2 pi)

? () → error; missing procedure
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? '(* 2 pi) → (* 2 pi)

? () → error; missing procedure

? '() → ()
```

Both Code and Data are S-Expressions

- We've mentioned how sexps are used to represent *both* data and code.
- Note the double role of lists:
- Lists are function calls:

```
? (* 10 (+ 2 3)) → 50
? (bar 1 2) → error; function bar undefined
```

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- Note the double role of lists:
- Lists are function calls:

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```

- But, lists can also be data:

```
? '(foo bar) → (foo bar)
? (list 'foo 'bar) → (foo bar)
```

LISP = LISt Processing

- `cons` builds up new lists; `first` and `rest` destructure them.

```
? (cons 1 (cons 2 (cons 3 nil))) → (1 2 3)
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- Many additional list operations (derivable from the above), e.g.

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? (append '(1 2) '(3) '(4 5 6)) → (1 2 3 4 5 6)
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```

- Many additional list operations (derivable from the above), e.g.

```
? (list 1 2 3) → (1 2 3)
? (append '(1 2) '(3) '(4 5 6)) → (1 2 3 4 5 6)
? (length '(1 2 3)) → 3
? (reverse '(1 2 3)) → (3 2 1)
```

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? (rest '(1 2 3)) → (2 3)
? (first (rest '(1 2 3))) → 2
? (rest (rest (rest '(1 2 3)))) → nil
```

- Many additional list operations (derivable from the above), e.g.

```
? (list 1 2 3) → (1 2 3)
? (append '(1 2) '(3) '(4 5 6)) → (1 2 3 4 5 6)
? (length '(1 2 3)) → 3
? (reverse '(1 2 3)) → (3 2 1)
? (nth 2 '(1 2 3)) → 3
```

LISP = LISt Processing

- `cons` builds up new lists; `first` and `rest` destructure them.

```
? (cons 1 (cons 2 (cons 3 nil))) → (1 2 3)
? (cons 0 '(1 2 3)) → (0 1 2 3)
? (first '(1 2 3)) → 1
? (rest '(1 2 3)) → (2 3)
? (first (rest '(1 2 3))) → 2
? (rest (rest (rest '(1 2 3)))) → nil
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? (length '(1 2 3)) → 3
? (reverse '(1 2 3)) → (3 2 1)
? (nth 2 '(1 2 3)) → 3
? (last '(1 2 3)) → (3)          Wait, why not 3?
```
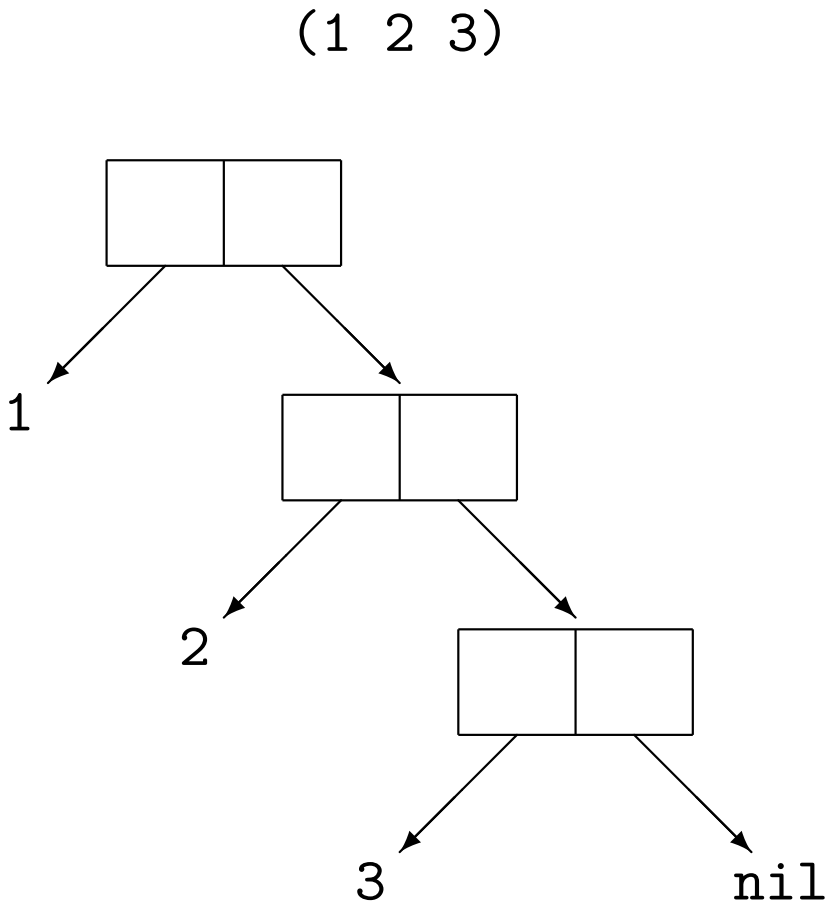

Lists are Really Chained 'cons' Cells




```
(cons 1 (cons 2 (cons 3 nil)))
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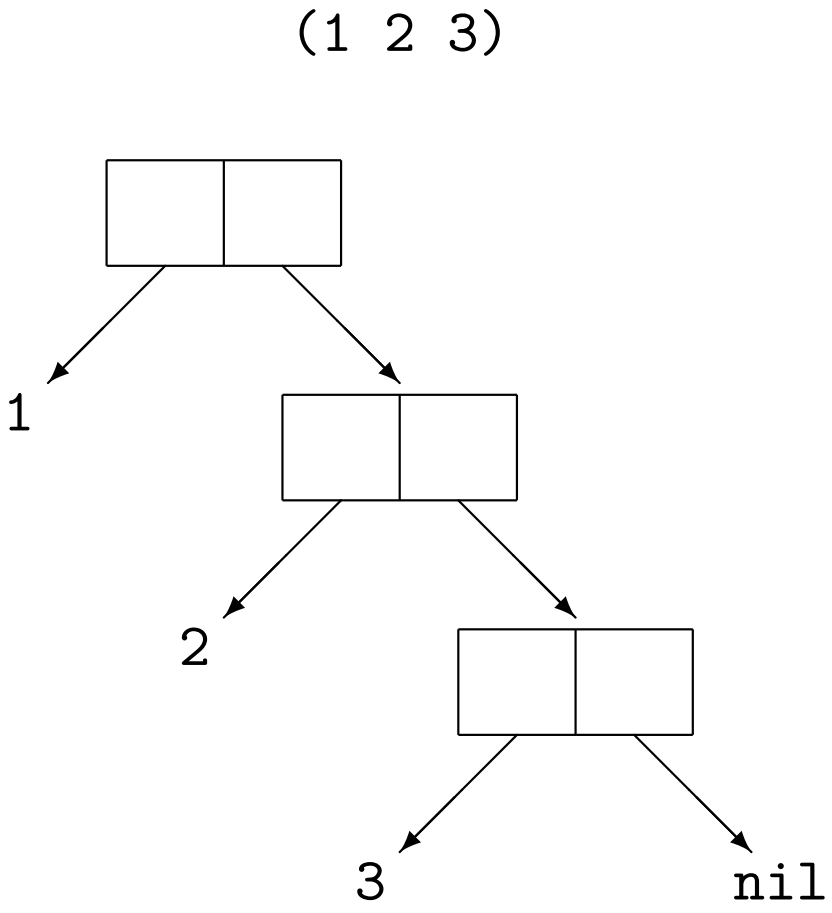

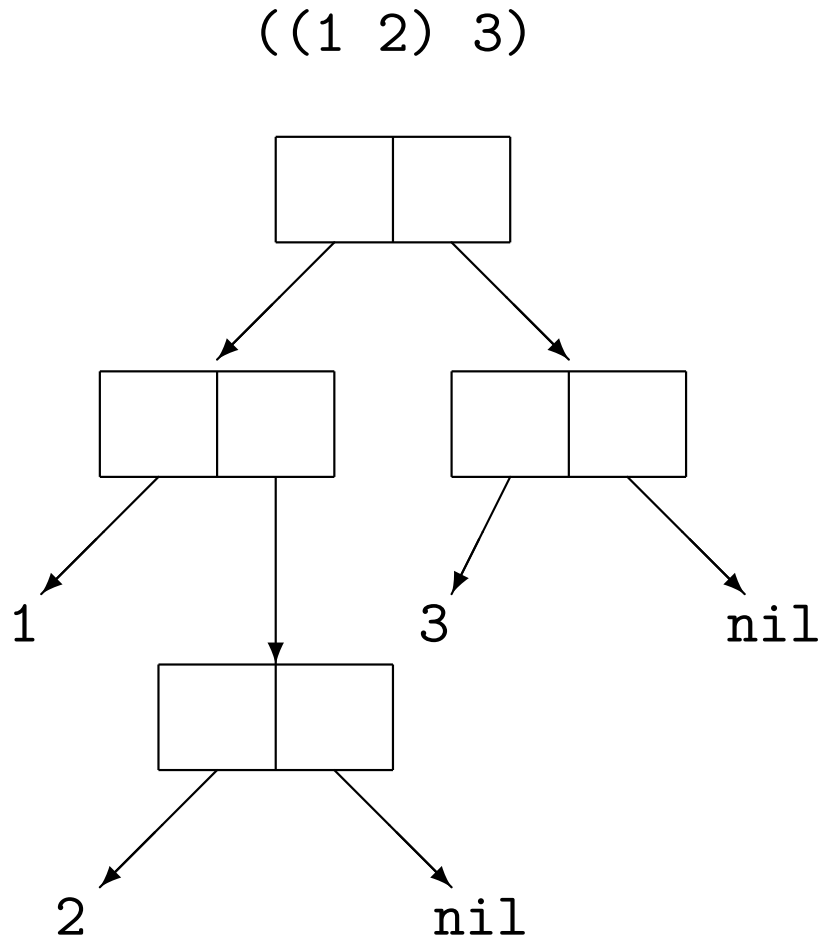


```
(cons 1 (cons 2 (cons 3 nil)))
```

```
(cons (cons 1 (cons 2 nil)) (cons 3 nil))
```

Assigning Values: ‘Generalized Variables’

- `defparameter` declares a ‘global variable’ and assigns a value:

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? (defparameter *foo* 42) → *FOO*
? *foo* → 42
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? *foo* → 43
```

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? *foo* → 43
? (setf *foo* '(2 2 3))
```

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? *foo* → 43
? (setf *foo* '(2 2 3))
? (setf (first *foo*) 1)
```

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```
? (setf *foo* (+ *foo* 1))
? *foo* → 43
? (setf *foo* '(2 2 3))
? (setf (first *foo*) 1)
? *foo* → (1 2 3)
```

Some Other Macros for Assignment

Example	Type of `x`	Effect
`(incf x y)`	number	`(setf x (+ x y))`
`(incf x)`	number	`(incf x 1)`
`(decf x y)`	number	`(setf x (- x y))`
`(decf x)`	number	`(decf x 1)`
`(push y x)`	list	`(setf x (cons y x))`
`(pop x)`	list	`(let ((y (first x))) (setf x (rest x)) y)`
`(pushnew y x)`	list	`(if (member y x) x (push y x))`

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`(decf x)`	number	`(decf x 1)`
`(push y x)`	list	`(setf x (cons y x))`
`(pop x)`	list	`(let ((y (first x))) (setf x (rest x)) y)`
`(pushnew y x)`	list	`(if (member y x) x (push y x))`

Shall we jointly write our own `push` and `pop`?

Local Variables

- Sometimes we want to store intermediate results.
- `let` and `let*` create temporary value bindings for symbols.

```
? (defparameter *foo* 42) → *FOO*

? (defparameter *bar* 100) → *BAR*

? (let ((*bar* 7)
        (baz 1))
    (+ baz *bar* *foo*))

→
```

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→ 50

? *bar* →
```

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→ 50

? *bar* → 100
```

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→ 50

? *bar* → 100

? baz →
```

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    (+ baz *bar* *foo*))

→ 50

? *bar* → 100

? baz → error; unbound variable
```

Local Variables

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- Bindings valid only in the body of `let`.
- Previously existing bindings are *shadowed* within the lexical scope.

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→ 50

? *bar* → 100

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```

- Bindings valid only in the body of `let`.
- Previously existing bindings are *shadowed* within the lexical scope.
- `let*` is like `let` but binds *sequentially*.

Predicates

- A *predicate* tests some condition.
- Evaluates to a boolean truth value:
  - `nil` (the empty list) means *false*.
  - Anything non-`nil` (including `t`) means *true*.

```
? (listp '(1 2 3)) → t

? (null (rest '(1 2 3))) → nil

? (evenp 2) → t

? (defparameter foo 42)

? (or (not (numberp foo))
      (and (>= foo 0)
           (<= foo 42))) → t
```

- Plethora of equality tests: `eq`, `eql`, `equal`, and `equalp`.

Equality for One and All

- `eq` tests object identity; not applicable for numbers or characters.
- `eql` is like `eq`, but well-defined on numbers and characters.
- `equal` tests structural equivalence (recursively for lists and strings).
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? (eq (list 1 2 3) '(1 2 3)) → nil
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```
? (eq (list 1 2 3) '(1 2 3)) → nil
? (equal (list 1 2 3) '(1 2 3)) → t
? (eq 42 42) → ? [implementation-dependent]
```

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? (eql 42 42) → t
? (eql 42 42.0) → nil
```

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? (eql 42 42.0) → nil
? (equalp 42 42.0) → t
? (equal "foo" "foo") → t
```

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? (equal "foo" "foo") → t
? (equalp "FOO" "foo") → t
```

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? (eql 42 42.0) → nil
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? (equal "foo" "foo") → t
? (equalp "FOO" "foo") → t
```

- Also many type-specialized tests like `=`, `string=`, etc.

Conditional Evaluation

Examples

```
? (defparameter foo 42)

? (if (numberp foo)
      "number"
      "something else")
```

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? (cond ((< foo 3) "less")
        ((> foo 3) "more")
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```

Conditional Evaluation

Examples

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? (defparameter foo 42)

? (if (numberp foo)
      "number"
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      "number"
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        ((> foo 3) "more")
        (else "equal"))
→ "more"
```

General Form

(if ⟨*predicate*⟩
    ⟨*then clause*⟩
    ⟨*else clause*⟩)

(cond (⟨$predicate_1$⟩ ⟨$clause_1$⟩)
      (⟨$predicate_2$⟩ ⟨$clause_2$⟩)
      (⟨$predicate_i$⟩ ⟨$clause_i$⟩)
      (t ⟨*default clause*⟩))

Rewind: A Note on Symbol Semantics

- Symbols can have values as functions and variables at the same time.
- #' (*sharp-quote*) gives us the function object bound to a symbol.

```
? (defun foo (x)
    (* x 1000))
```

Rewind: A Note on Symbol Semantics

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```
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    (* x 1000))

? (defparameter foo 42) → 2
```

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? (defparameter foo 42) → 2

? (foo foo) →
```

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? (foo foo) → 42000
```

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? (foo foo) → 42000

? foo → 42
```

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- #' (*sharp-quote*) gives us the function object bound to a symbol.

```
? (defun foo (x)
    (* x 1000))

? (defparameter foo 42) → 2

? (foo foo) → 42000

? foo → 42

? #'foo → #<Interpreted Function FOO>
```

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- #' (*sharp-quote*) gives us the function object bound to a symbol.

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? (defparameter foo 42) → 2

? (foo foo) → 42000

? foo → 42

? #'foo → #<Interpreted Function FOO>

? (funcall #'foo foo) → 42000
```

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? (defun foo (x)
    (* x 1000))

? (defparameter foo 42) → 2

? (foo foo) → 42000

? foo → 42

? #'foo → #<Interpreted Function FOO>

? (funcall #'foo foo) → 42000
```
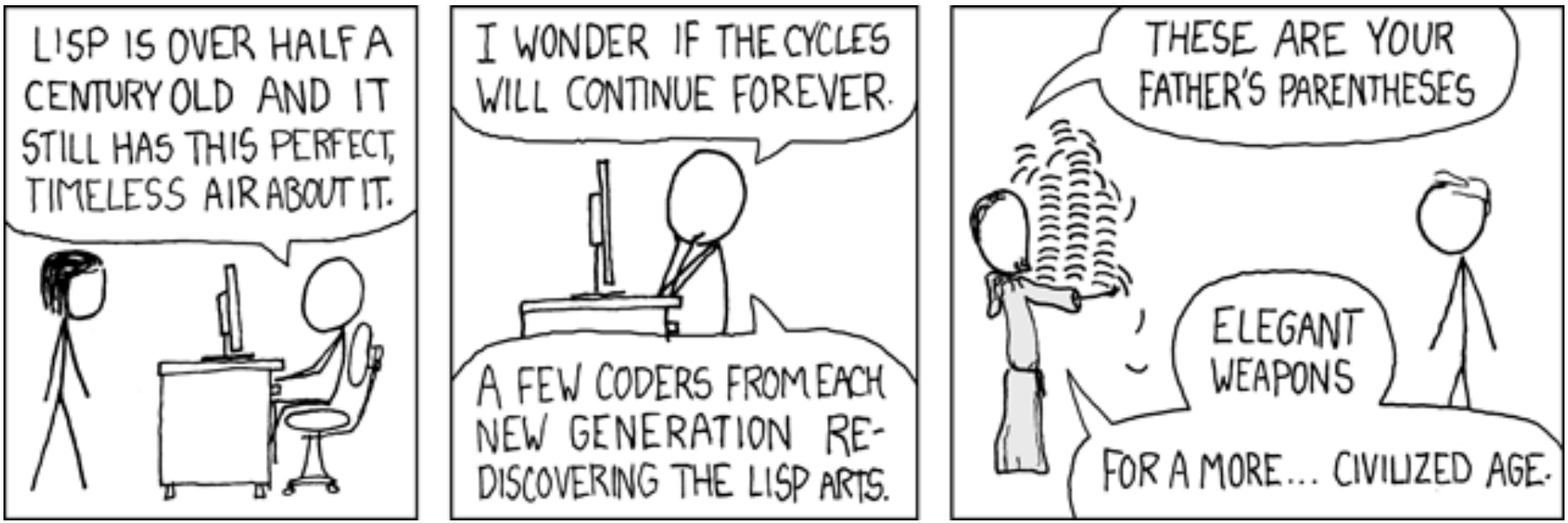

- `#'` and `funcall` (as well as `apply`) are useful when passing around functions as arguments.

In Conclusion



http://xkcd.com/297/

Next Week

More Common Lisp.

- More on argument lists (optional arguments, keywords, defaults).
- More data types: Hash-tables, a-lists, arrays, sequences, and structures
- More higher-order functions.
- Iteration (`loop`) and mapping.