G22.2210

Programming Languages: PL

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Functional Programming

- **Pure Functional Programming**:
  Implicit Principle

  ∘ The value of an expression depends only on the values of its subexpressions, if any.

  - No side-effect. (No State—No assignment)
  - An expression has the same value, every time.
  - Implicit Storage Management:
    Allocation on Demand + Garbage Collection.
  - Functions are **First Class Objects**:
    1) As value of an expression
    2) As parameters
    3) As data Objects.

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Common Lisp

- LISP: LIst Processing Language
  Not— Lots of Insidious Sill Parentheses
- Second oldest Programming Language (After Fortran)
- Application Areas:
  1. Theorem Proving
  2. Symbolic Algebra
  3. AI (Artificial Intelligence)
     (Natural Language Processing, Computer Vision, Robot Control Systems, Expert Systems, Neural Networks, Automatic Programming)

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HISTORY

- Developed at MIT AI Lab—1959.
  LISP 1.5 running on an IBM machine.
- BBN LISP (PDP 1/SDS 940) became → INTERLISP (PDP 10)
- MACLISP (MIT Project MAC)
- LISP 1.6—A version of MACLISP
  - UCI-LISP (Univ. of Cal. at Irvine)
  - Standard Lisp (Univ. of Utah)
- Lisp Machine Lisp
  Large Personal Lisp Machine built at MIT
- FranzLISP for Vax/UNIX (UC Berkeley)
- NIL for Vax/VMS (MIT)
- Scheme at MIT
- T Lisp at Yale

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Common Lisp

- 1981/Carnegie-Mellon/Guy L. Steele
- **Clean Lisp**

  Inconsistencies and illogical conventions were resolved

- **Transportable**

  Programs written in Common Lisp and debugged in one implementation should run on another machine/implementation without change.

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Lisp Data & Functional Objects

- Lisp Programs and the data have Same form
  - Self-modifying Lisp programs.
  - Embedded languages in Lisp
- Lisp functions are data objects that can be passed as parameters to other functions
  - Extensible control structures
- Interpreter + Compiler
- Garbage Collector

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Lisp Objects

- **Lisp Objects**
  1. ATOMS
     (a) Numbers: $\{3, -5.7, 2010014567\}$
     (b) Symbols: { `A`, `EVAL`, `PI`, `T`, `NIL` }
  2. CONS
     Conjunctions of two Lisp objects. Each of them may be a CONS object or an ATOM.
- Example

```
(CONS ´A ´B)
(CONS ´2 (CONS ´BAD ´NIL))
```

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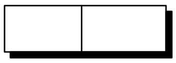
CONS Cells

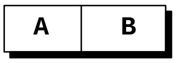


= =Two Compartments...
Each compartment holds an atom or a cons object (A pointer to a cons cell.

- **(CONS 'B 'NIL)**

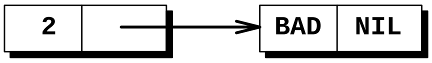
(B)

- **(CONS 'A 'B)**

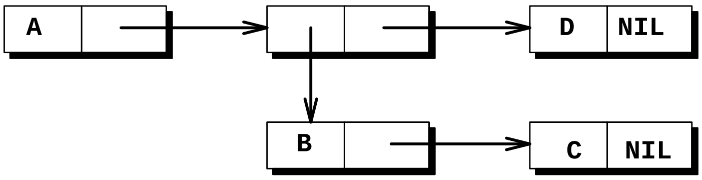


(A . B)

- **(CONS '2 (CONS 'BAD 'NIL))** **(2 BAD)**



- **(CONS 'A (CONS**
  (CONS 'B (CONS 'C 'NIL))
  (CONS 'D NIL)
)



(A (B C) D)

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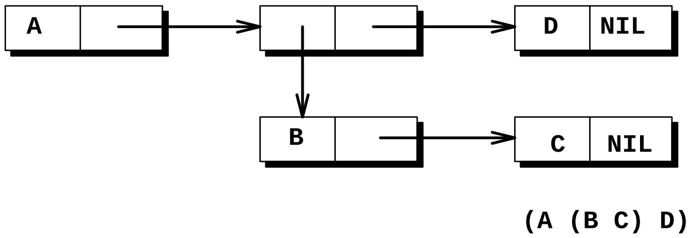
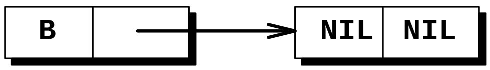
LISTS

- Function LIST

```
   (LIST ´A (LIST ´B ´C) ´D)
=> (A (B C) D)
```




```
   (LIST ´B NIL)
=> (B NIL)
```




```
   (LIST)
=> NIL
```

(An Atom not a CONS cell)

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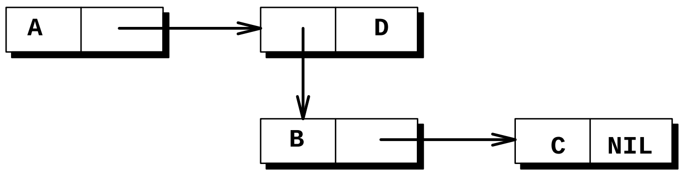
Proper and Improper Lists

- **Proper Lists**
  Lists terminating in NIL
- **Improper Lists**
  Lists not terminating in NIL

```
(A (B C) . D)
```



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List Operations

- CAR: Extracts the *first* element of a list
- CDR: Extracts the *rest* (all but the first element) of a list
- CAR & CDR can be applied to any list, but not to atom other than NIL

$$(CAR\, NIL) \equiv (CDR \quad NIL) \equiv NIL$$

- **Examples**

```
(CAR ´(A B C))                           => A
(CDR ´(A B C))                           => (B C)
(CAR (CDR (CAR (CDR ´(A (B C) D)))))     => C
```

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List Predicates

- Boolean-valued functions

  {`T` = True, `NIL` = False }
- `ATOM`: True iff an atom

```
(ATOM ´NIL)                  =>   T
(ATOM ´(X Y))                =>   NIL
```

- `CONSP`, `LISTP`, . . .
- `NULL`: True iff an empty list (e.g., `NIL`)

```
(NULL ´NIL)                  =>   T
(NULL ´X)                    =>   NIL
```

- `ZEROP`, `NUMBERP`, . . .

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Conditional Form

- `IF` & `COND`

```
(IF <test-predicate> <then-clause> <else-clause>)
(COND (<test-1> <result-1>)
      (<test-2> <result-2>)
      ...
      (<test-n> <result-n>)
      )
```

- `IF` form is equivalent to

```
(COND (<test-predicate> <then-clause>)
      (T <else-clause>))
```

- When the LISP evaluation procedure sees a `COND`, it evaluates each of the test forms in order (i.e., `<test-1>`, `<test-2>`, ...

- When one evaluates to "non-`NIL`," its corresponding result form (i.e., `<result-i>`) is evaluated and its value is returned as the result of the `COND`.

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Simple Examples

- **Example**

```
(IF (ATOM ´X) ´YES ´NO)                   =>   YES

(COND ((ATOM ´X) ´YES)
      (T ´NO))                            =>   YES

(DEFUN LENGTH (LIST)
      (IF (NULL LIST)
          0
          (+ 1 (LENGTH (CDR LIST)))))
```

- LENGTH Computation

```
    (LENGTH ´())                          =>   0

    (LENGTH ´(C))
=   (+ 1 (LENGTH ´()))                    =>   1

    (LENGTH ´(B C))
=   (+ 1 (LENGTH ´(C)))                   =>   2

    (LENGTH ´(A B C))
=   (+ 1 (LENGTH ´(B C)))                 =>   3
```

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LISP EVALUATOR: `EVAL`

LISP Obj $\Rightarrow$ S-expression (Symbolic Expn)
$\mapsto$ Values

Evaluation Order = "Inside-Out"

- Atoms evaluate to themselves:
  Numbers and `NIL` are constants and have predefined values. Symbols can be `SET` to a value in the course of execution.

```
(SET 'A '(X Y))                   =>  A = (X Y)
```

- List to be evaluated must have a "functional-valued" symbol as its `CAR`. The `CDR` of the list is treated as the arguments.
  Evaluation proceeds by applying the function (`CAR`) to the argument (`CDR`)

```
(+ 2 4)                           =>  6
(+ (CAR (CDR (LIST 2 3))) 4)      =>  7
```

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QUOTE

- Evaluation Blocker
  - If the symbol in the functional position is a *special form*, then the usual evaluation rule is replaced by a special one *before* the arguments are evaluated
  - `QUOTE` $\equiv$ Special Form

A quoted item evaluates to itself

```
(QUOTE A)                    => ´A
(QUOTE (A B (QUOTE C) D)     => ´(A B ´C D)
```

- **Example**

```
(SET ´PI 3.1415)              =>  PI = 3.1415
                              =>  ´PI = PI

(SETQ B ´X)
(SET B ´Y)                    =>  B = X
                              =>  X = Y
(CONS 3 ´(+ 5 6))             =>  (3 + 5 6)
(+ ´3 ´4)                     =>  7
```

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EVAL

- Evaluation procedure can be invoked directly

```
   (SETQ A (LIST ´+ 5 6))      =>  A = (+ 5 6)

   (CONS A ´(IS MY RESULT))
=> ((+5 6) IS MY RESULT)

   (CONS (EVAL A) ´(IS MY RESULT))
=> (11 IS MY RESULT)
```

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USER-DEFINED FUNCTIONS

```
(DEFUN <function-name> <argument-list> <body>)
```

- `DEFUN`

  Special Form: subforms are not evaluated as arguments

- `<function-name>`

  Must be a symbol. Can be any symbol other than `NIL`

- `<argument-list>`

  Number of Symbols in the argument list is the number of arguments the function must be handed by the `EVAL` procedure

- `<body>`

  An S-expression that will be evaluated when the function is called... After appropriate substitution of the actuals for formals.

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Examples: APPEND & REVERSE

```
(DEFUN APPEND (X Y)
   (IF (NULL X)
       Y
      (CONS (CAR X) (APPEND (CDR X) Y))))
```

```
(DEFUN REVERSE (LIST)
   (IF (NULL LIST)
       ´NIL
       (APPEND (REVERSE (CDR LIST))
               (CONS (CAR LIST) ´NIL))))
```

[End of Lecture #11]