CMPUT325 Extensions to Pure Lisp

Bob Price and Russ Greiner

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Extensions to Pure Lisp

- "Extensions" to Pure *Lisp*
  - Side Effects (setq, putprop, . . .)
  - Numbers
  - Dotted-Pair, Association & Property Lists
  - *Lisp qua* Procedural Language (i/o, do, ...)

No Side Effects

```
(+ 11 23) →  34
(CAR '(A B C))→  A

(+ 11 23) →   34

(+ (* X 2) 5) →  X undefined
(+ 11 23) →  34

(CAR '(A B C)) →  A
(+ (* X 2) 5)} →  X undefined
```


Side-Effect Free — Def'n

- Form σ has NO side effects if
  Evaluating σ does not affect the value of any other expression τ.
- Hence: Value of form τ is the same
  whether or not σ was evaluated .

  → $\underline{\tau}$

  ⟨v1⟩

  → $\underline{\sigma}$

  ⟨v2⟩

  → $\underline{\tau}$

  ⟨v1⟩
- Examples: Any form using only +, CAR, CONS, . . .

Functions with Side Effects – SETQ

```
my-const → undefined variable
(SETQ my-const '(A B C)) → (A B C)
my-const → (A B C)
(CAR my-const)→ A
(SETQ my-const '(t 4)) → (t 4)
my-const→ (t 4)
(CAR my-const) → t
```


The mysterious SETF

- SETF chooses a modifier function according to its first argument

```
(SETF x '(1 2 3))→
(1 2 3) ;;≡(SETQ x '(1 2 3))
X → (1 2 3)

(SETF (car x) 'a) → (a 2 3) ;; ≡(RPLACA x 'a)
X →  (a 2 3)

(SETF A (make-array '(2 2)))
→ #2A((NIL NIL) (NIL NIL))

(SETF (aref A 0 0) 'q)
→ #2A((Q NIL) (NIL NIL))
```

Functions with Side Effects – SETF

```
( (LAMBDA (X) (CDR X)) '(A B C) ) → (B C)
( (LAMBDA (X) (CDR X)) '(Q t) ) → (t)
(setf (symbol-function 'my-fn)
    (FUNCTION (LAMBDA (X) (CDR X))) )
→ (LAMBDA-CLOSURE ...(X) (CDR X)))
(my-fn '(A B C)) → (B C)
(my-fn '(Q t)→ (t)
(my-fn (my-fn my-const)))→ (C)
(setf (symbol-function 'my-fn)
    (FUNCTION CAR) )
    → #<complied-function car>
 (my-fn '(A B C)) → A
```


Functions with Side Effects – SETF

```
(setf (symbol-function '+)
      (symbol-function '-)) ;; DON'T DO THIS!!

(setf (symbol-function 'bye)
(FUNCTION (LAMBDA () "Not so quick bit brain!")))
```

- Simultaneous assignment

```
(setf a 1 b 2 c 3)
a →1
b →2
c →3
```

User-Defined Function with Side Effects

```
(SETQ my-var 5) → 5
my-var→ 5
(SETF (symbol-function 'fn2)
      '(LAMBDA (X) (SETQ my-var X)) ) →
(LAMBDA (X) ...)
my-var → 5
(fn2 '(A B C)) → (A B C)
my-var → (A B C)
(fn2 (LIST (+ 3 4)))→ (7)
my-var→ (7)
```


SETF symbol-function and DEFUN

- (DEFUN name (v_1 ... v_n) ⟨form⟩) is an ABBREVIATION for

```
(SETF (symbol-function name)
 (FUNCTION (LAMBDA (v1 ... vn) ⟨form⟩)))
```

The SETQ Function

- SETQ does NOT evaluate its first argument.

```
(SETQ b '5)
B → 5
X → undefined
(setq x 'b) → B ;; Not an error!
X→B
B →5 ;; but B's value unchanged.
```


The SET Function

- SET DOES evaluate its first argument.

```
B → undefined
X → undefined
(set X '(foo bar)) → x undefined
(set 'X '(foo bar)) →(foo bar) ;; Now X ←(foo bar)
(setq X 'B) → B ;; Now X ←B
X → B
(set X (+ 100 12))→
112  ;;Note: Changes value of X's value (B)
X → B
B → 112
```

Numbers in Lisp

- *Numbers* are special atoms: (Each evaluates to itself.)

```
5 → 5
(list 5 'a) → (5 a)
;; don't need quote for numbers
```

- `Numberp` tests whether an s-expr is a numeric atom.

```
(numberp 12) → t
(numberp 'a) → nil
(setq n 25)
(numberp n) →
t    ;; numberp evaluates its arguments
(numberp '(1 2)) → nil
```


Types of Numbers in Lisp

- Rational
  - Integers
    - Fixnums
    - Bignums
  - Ratios
- Floats
- Complex Floats
- No irrationals!!

Integers

- There is no apriori limit on size of an integer

```
(expt 2 5) → 32
(expt 2 100)
→ 1267650600228229401496703205376
```

- Smaller numbers are more efficient
  - Called "fixnums" and guaranteed to range at least $(-2^{16}, 2^{16})$
- Storage is automatically added as required
  - Large integers are called "bignums"
- Generally transparent to programmer
- Can use arbitrary (well 2 to 36 anyway) radices to enter a number

```
#10r15 → 15   #2r1111 → 15   #3r120 → 15
```


Ratios, Floats

- Exact ratios can be represented without roundoff error

```
(expt (/ 2 3) 2) → 4/9
```

- As in other languages, floating point numbers are represented as follows

```
5.2
6.02E+23
5E-22
```

- Control over precision of floating point numbers is available

Complex Numbers

- Complex numbers have their own notation in Lisp

```
#C( real imaginary )
1-2i = #C(1 -2)
```

- Many Lisp functions will take complex arguments

```
(* #c(0 -1) #c(0 -1)) → 1

pi →3.1415926535897932385L0
(exp (* #c(0 -1) pi))
→ #C(-1.0L0 5.0165576136843360246L-20) ≈ -1
```

(i.e., the Euler identity $e^{i\pi}$=-1)

Numerical Operations

- Unlike most languages, basic arithmetic op's are n-ary: + * - /

```
(+ 1 2 3 4 5 6 7 8 9 10) → 55
(* 2 2 2) → 8
(- 10 1 ) → 9
(- 10 1 3) → 6
(/ 12 3 4) → 1
```

- Binary Functions: MOD

```
(MOD 11 2) → 1
```

Numerical Operations

- Unary Functions:

```
(1+ 3) → 4
(1- 3) → 2
(ABS -2) → 2
(SIN (/ pi 2)) → 1.0L0 ;; returned  a float
(COS (/ pi 2)) → -2.5082788076048218878L-20 ≈0
```

- Binary Predicates: `<` `>` `>=` `<=`
- Unary Predicates: `ZEROP`

Numbers Are Not Always EQ!

- Numbers are atoms:

```
(atom 5) →T  (atom 4.0) →T  (atom #C(1 -1)) →T
```

- Recall: equivalent items (e.g., eq) vs. equal items (e.g., equal)
- For efficiency use mathematical equality (e.g. =)
- Numbers are atoms, but are not always eq of each other

```
(= 4 4.0) →  T
(eq 4 4.0) → nil  ;; mathematically equal

(= 1234567890 1234567890 ) → T
(eq 1234567890 1234567890 ) →
nil ;; distinct bignums
```

Association Lists

- An **Association List** is a list of DOTTED-pairs where:
  `CAR` of each DOTTED-pair is attribute
  `CDR` of each DOTTED-pair is value.

- Eg:

```
( (name      . (Bart Selman))
  (hair      . black)
  (children  . ( (Mary Louise)
                 (Jean Pierre) ) )
  (habits    . nil) )
```


Dotted-Pair

- `CONS` can really take ANY pair of S-expressions
- earlier, just dealt with atoms and lists
- Value of `(CONS s1 s2)` is `(s1 . s2)`
  for any `s1, s2` $\in$ s-expr

`(cons 'a 'b)` $\rightarrow$(a . b)

`(cons 4 '(a b c))` $\rightarrow$`(4 . (a b c))`

`(cons '(t) '(a . b))` $\rightarrow$`((t) . (a . b))`

`(cons 4 '(a . b))` $\rightarrow$`(4 . (a . b))`

- Retreiving components

`(CAR '(a . b))` $\rightarrow$a

`(CAR (CONS 'a 'b))` $\rightarrow$a

`(CDR '((t) . (a . b)))` $\rightarrow$(a . b)

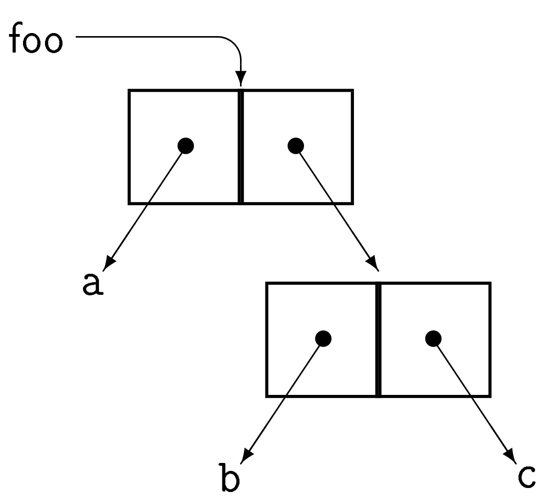
Notation

- Can write `(s`$_1$` . (s`$_2$` ...))` as `(s`$_1$` s`$_2$` ...)`
  Hence `(a . (b . c))` $\mapsto$ `(a . (b . c))`
- Can write `(s`$_1$` s`$_2$` ...s`$_n$` . nil)` as `(s`$_1$` s`$_2$` ...s`$_n$` )`
  Hence `(cons 'a nil)` $\mapsto$ `(a . nil)` $\mapsto$ `(a)`
- Notice:
  When `CONS`'s 2nd arg is list, just as before!

Dotted Pair – Internals

`(SETQ foo (CONS 'a (CONS 'b 'c)))`

(a . (b . c))



Association Lists

- Can be assigned:
  (setq bart '((name Bart Selman) (hair . black)
  (children (Mary Louise) (Jean Pierre))
  (habits)))

The ASSOC Function

- `ASSOC` takes two arguments
  Attribute (an atom)
  Alist (an association list)
  returns *entire* Dotted-Pair if match is found.

```
(assoc 'name bart) →(name Bart Selman)
(assoc 'children bart)
 →(children (Mary Louise) (Jean Pierre)
(assoc 'habit bart) →(habit)
(assoc 'mother bart) →nil
(CDR (assoc 'name bart)) → (Bart Selman)
```

- Requires $2n$ `CONS`-cells overhead

The ASSOC Function

- The equality test in assoc can be changed with the `:test` parameter

```
(assoc '(a) '( ( (a) . 1 ))) → NIL
(assoc '(a) '( ( (a) . 1 )) :test 'equal)
→((A) . 1)
```

- A key pure list data structure:
  - New entries can "shadow" old entries (functional modification)
  - Tails of assoc lists can be shared
  - Allows access to values by named key like a structure
- Convenience functions make it easy to manage

Other Association List Functions

- The `rassoc` function (reverse associate) returns an *entry* given a value

```
(rassoc '(Bart Selman) bart) →
(name (Bart Selman))
```

- The acons functions creates a new entry

```
(acons 'age 42 bart) ≡(cons (cons 'age 42) bart)
```

- The pairlis function zips two lists together into a association list

```
(pairlis '(1 2 3) '(a b c))
→ (  (1 . a) (2 . b) (3 . c) )
```

General List Functions

- The some and every function take n lists and pass the corresponding elements of each list to an n-ary predictate

```
(some predicate sequence1 sequence2 ...)
```

- The some function returns true if any element of a list(s) satisfies predicate

```
( (some #'(lambda (x y)   (not (equal x y)))
        '(1 2 3) '(1 2 4)) → T
```

- The every function returns true if every element of a list(s) satisfies pred

```
( (every #'(lambda (x y)   (equal x y))
        '(1 2 3) '(1 2 4)) → nil
```


General List Functions

- The `find` function returns the first element that matches item, or `nil`

```
(find item sequence)
;; recall any non-nil value is true
(find 'a '(c b a)) →A
(find 'a '(c b)) →nil
```

- The `find-if` function returns the first element that satisfies a predicate

```
(find-if #'oddp '(2 4 7 6 9)) → 7
```

- Many other functions

```
position, mismatch, substitute, remove, sort
```

General List Functions

- There is an overlap with assoc

```
(assoc item list :test fn)
   ≡ (find item list :test fn :key #'car)
```


General List Functions

- More list functions

```
(member 1 '(1 2 3)) →
(1 2 3) ;; i.e., non-nil
(union '(1 2 3) '(2 3 4)) → (1 2 3 4)
(intersection '(1 2 3) '(2 3 4)) →(2 3)
(adjoin 2 '(1 2 3)) →(1 2 3)   ;; add if absent
(adjoin 4 '(1 2 3)) → (4 1 2 3)
```

- *Destructive* List Functions

```
(setf x '(1))
(push 2 x)
x →(2 1)
(pop x) → 2
x → (1)
```

Property Lists

- Like association lists, but
  - attached to specific symbol and
  - operations are destructive

```
(setf (get 'clyde 'species) 'elephant)
(setf (get 'clyde 'age) 42)
(get 'clyde 'species) → elephant
(get 'clyde 'age) → 42
(remprop 'clyde 'age)
(get 'clyde 'age) → nil
```

- Do not delete plist as some implementations store important information about symbols in their plists
-

Hash Tables

- Hash tables allow efficient storage and retrieval by keys
- Have a state and are subject to side effects

```
(setq pops (make-hash-table)) → #S(HASH-TABLE EQL)
(gethash 'calgary pops) → nil; nil
```

- Note: gethash returns 2 values
  - second value is T or nil if key was found or not
  - allows one to distinguish between not found, and found value nil
- Use multiple value bind to catch both values

```
(multiple-value-bind (value ok) (gethash 'calgary pops)
   (if ok <form> ))
```

Hash Table Functions

- Setting entries in a table

```
(setf (gethash 'calgary pops) 876519) → 876519
(gethash 'calgary pops) → 876519
```

- The test used to match keys can be set with :test
- Other useful hash table functions

```
(remhash 'calgary)  ;; removes entry

;; applies fn to each key-value
(maphash fn hash-table)  pair
```


Vectors and Arrays

- Construction and use of a vector

```
(setf u #(2 3 4))
u →
#(2 3 4)   ;; macro constructor is convenient
(setf v (vector 1 2 3))
v → #(1 2 3)
(setf (aref v 0) 9) →9  ;; index from zero
v → #(9 2 3)
```

- Matricies

```
(setf m (make-array '(2 2)))
→ #2A((NIL NIL) (NIL NIL))
(setf (aref m 0 0) 9) → 9
m → #2A((9 NIL) (NIL NIL))
```

Structures

- DEFSTRUCT defines methods for creating and accessing elements of a new structure

  `(DEFSTRUCT course name room time)`

- The methods `make-course`, `course-name`, `course-room` and `course-time` are now defined

```
(setq cmput325 (make-course))
→ #S(COURSE :NAME NIL :ROOM NIL :TIME NIL)

(setq (course-name cmput325)
     "Non-procedural progamming")

(course-name comput325) →"Non-procedural progamming"
```

- Can be compiled to efficient memory accesses

Lisp Objects: CLOS

- CLOS = Common Lisp Object System
- Provides functions for defining class data & methods
  - powerful shortcuts for defining initial values, accessors, etc.
- Supports multiple inheritance
- Can define your own method dispatching behaviours through the meta-object protocol
- Can flexibly call super-class code anywhere is a method

Lisp Objects: Classes

- Class definintion provides a rich language
- A class with a slot named "color"

```
(defclass shape ()
   ((color :accessor color
           :initarg :color
           :initform 'clear)))
(setf s1 (make-instance 'shape :color 'red))
(color s1) → red
```


Lisp Objects: Inheritance

- Inheritance

```
(defclass circle (shape)
    ((center :accessor center
         :initarg :center
         :initform (list 0 0))
     (radius :accessor radius
             :initarg :r
             :initform 1)))
```

Lisp Objects: Methods

- Methods defined through generic functions with typed arguments

```
(defmethod draw ((c circle))
    (format t "Circle color:~s~% " (color c) ))
```


Lisp Strings

- Strings are built of characters which are introduced with #\

```
#\g #\G  ;; these are different!
#\space #\newline #\linefeed #\page
#\return #\backspace #\rubout
```

- Can be constructed as constants or dynamically

```
(setf name "bob")
(setf label (make-string 10 :initial-element #\B))
→ "BBBBBBBBBB"
```

- Can be compared by equal or for dictionary ordering with string= string> etc.

Basic IO

- `(read stream)` – reads an s-expr from stream
- `(write object stream)` – writes s-expr to stream
- `(terpri)` – flushs buffer, prints carriage return
- `(load ⟨file⟩)` – loads file named ⟨file⟩.

I/O in Lisp – Input

- Use (read stream) to read from stream
- Read one complete s-expr at a time
- Use t for the console stream

```
(sqrt (read t))
49  ;; user typing
→7
(car (setq x (read t)))
'(a b c) ;; user typing
→ A
```

I/O in Lisp – Output

- Use (print object stream) to write object to stream
- Writes one complete s-expr at a time
- Use t for the console stream or leave out stream

```
(print 44)
44 ;; output on console
```


I/O in Lisp – Formatted Output

- `FORMAT` is like printf in C or format in Fortran
- The basic form:
  `(FORMAT stream control-string arg1 arg2 ... argn)`
- The control-string is a template into which arguments are substituted
- Use t to indicate the console stream

I/O in Lisp – Formatted Output

```
(setf name "Fred" age 24)
(setf hobbies '("lambda calculus" "meta-programming"))
(format t
   "Meet ~s, aged ~s who enjoys ~s ~%"
   name age hobbies)
```

Meet "Fred", aged 24 who enjoys ("lambda calculus" "meta-programmi

I/O in Lisp – Control String

Control	Description
~s	print arbitrary s-expr in default form
~a	print s-expr in ASCII form
~%	insert carriage return
~nS	pad output of s-expr to make n-char field
~n,dF	fixed floating point with field width n and decimals d
~n,dE	exponential or scientifc notation
~n,dG	choose most appropriate of F or E

I/O in Lisp – Control Strings

```
(format t "~10s ~10s ~10s ~%" 'betty 'sal 'margaret)
(format t "~10s ~10s ~10s ~%" 'june 'sandy 'may)
BETTY      SAL        MARGARET
JUNE       SANDY      MAY
```


I/O in Lisp – Output to strings

- Turning objects into strings

```
(setf result (make-string-output-stream))
(format result "~s calculated PI to 2 decimals: ~3,2F ~%
   'norman pi)
(get-output-stream-string result)
→ NORMAN calculated PI to 2 decimals: 3.14
```

- Turning strings into objects

```
(read-from-string string)
```

Error Handling

- Common Lisp supports a complete error condition signalling system with catch and throw
- The simplest error handling is to call "error" which has the same syntax as "format"

  ```
  (error "Object ~s is unknown." an-object)
  ```

- The error invokes the debugger whereopon the user can use :bt to examine the backtrace leading to the bug

Basic IO

- `(terpri)` – flushs buffer, prints carriage return
- `(load ⟨file⟩)` – loads file named `⟨file⟩`.

VT100 Console Tricks

```
(defun clear-screen ()
   (let ((string (make-string 7)))
    (setf (aref string 0) #\Escape)
    (setf (aref string 1) #\[)
    (setf (aref string 2) #\2)
    (setf (aref string 3) #\J)
    (setf (aref string 4) #\Escape)
    (setf (aref string 5) #\[)
    (setf (aref string 6) #\H)
    (princ string)))
```


VT100 Console Tricks

```
(defun home-screen ()
  (let ((string (make-string 3)))
   (setf (aref string 0) #\Escape)
   (setf (aref string 1) #\[)
   (setf (aref string 2) #\H)
   (princ string)))
```

PROGN Form

- (progn ⟨form$_1$⟩ ⟨form$_2$⟩ ⋯ ⟨form$_m$⟩)
  Evaluates all forms, ⟨form⟩$_i$ $(i = 1..m)$
  in order.
- Returns value of final form, ⟨form⟩$_m$
  (Ignores other values)
- Takes ANY number of forms

LAMBDA Form with Side-Effects

- Common Lisp permits multi-form bodies:

  (LAMBDA (a1 ... an) form1 ... form_m)
- returns value of final form, ⟨form⟩$_m$.
- Only makes sense if forms preceding last have meaningful side-effects

```
(LAMBDA (a) (print a) (setq x a) (+ a 3)) 19)
19         ; printed by (print a)
→ 22    ; value of this form
x →  19 ; side effect causes new x value
```

The Truth about COND

- Earlier, insisted that each COND "clause" take exactly 2 forms. but, ... can take any number, from 1 on.

$$
\begin{array}{lllll}
\texttt{(COND} & (\langle q_1^1 \rangle & \langle q_2^1 \rangle & \cdots & \langle q_{m1}^1 \rangle) \\
 & (\langle q_1^2 \rangle & \langle q_2^2 \rangle & \cdots & \langle q_{m2}^2 \rangle) \\
 & & \cdots & & \\
 & (\langle q_1^n \rangle & \langle q_2^n \rangle & \cdots & \langle q_{mn}^n \rangle)\ )
\end{array}
$$

  where each $\langle q \rangle_j^i$ is a form, $mi \in \mathcal{Z}^+$.

- If $\langle q \rangle_1^i$ is nonNIL, Then evaluate $\langle q \rangle_j^i$ forms, for $j = 2 .. mi$.

- Return value for final form $\langle q \rangle_{mi}^i$.

- If $mi = 1$, and if $\langle q \rangle_1^i$ is nonNIL, then return $\langle q \rangle_1^i$'s value.

Example of Real COND

```
(defun swp (y)
   (COND ( x )
      ( y (print "x was nil, is now")
          (print (setq x y))
          (terpri) 7) ) )
(setq x 'fred)→fred
(swp 18)
fred ; just prints out value of x.
(setq x nil) → nil
(swp 18)
x was nil, is now 18  ; prints msg, and resets x
x →18                 ; value that form returns.
(setq x nil)→ nil
(swp nil)→nil ; COND fails.
```

LOOP Construct by Simple Examples

```
(LOOP FOR i FROM 1 TO 10
   DO (FORMAT t "~s " i))
⇝ 1 2 3 4 5 6 7 8 9 10 ; on console
→ nil   ; returned as value

(LOOP FOR i FROM 1 TO 10
   COLLECT i)
→(1 2 3 4 5 6 7 8 9 10)

(LOOP REPEAT 10     ;; constrains max iterations
   DO (format t "*"))
⇝ **********
→nil
```


LOOP Construct by Simple Examples

```
(LOOP FOR i FROM 1 TO 10 REPEAT 5
   COLLECT i)
→(1 2 3 4 5)
(LOOP FOR i FROM 10 DOWNTO 1 COLLECT i)
→(10 9 8 7 6 5 4 3 2 1)
```

LOOP Construct by Simple Examples

```
(LOOP FOR i FROM 10 DOWNTO 1 BY 2 COLLECT i)
→(10 8 6 4 2)

(LOOP FOR i IN '(10 9 8 7 6 5 4 3 2 1)  collect i)
→(10 9 8 7 6 5 4 3 2 1)

(LOOP FOR i IN '(10 9 8 7 6 5 4 3 2 1)
   BY 'cddr collect i)
→(10 8 6 4 2)
```


LOOP Construct by Simple Examples

```
(LOOP FOR i from 10 downto 1
      FOR j from 1  to 10
      WHILE (> i j) collect (CONS i j) )
→ ((10 . 1) (9 . 2) (8 . 3) (7 . 4) (6 . 5))

(LOOP FOR item = 1 THEN (+ item 10)
   REPEAT 5 COLLECT ITEM) →(1 11 21 31 41)

(loop for ch across #( 4 3 2) collect ch)
→ (4 3 2)
(loop for ch across "able" collect ch)
→ (#\a #\b #\l #\e)
```

Examples of LOOP

```
(LOOP FOR i from 1 to 10
   when (evenp i) collect i)
→ (2 4 6 8 10)

(LOOP FOR i from 1 to 10
   when (evenp i) collect (cons 'even i)
   when (oddp i)  collect (cons 'odd i))
→ ((ODD . 1) (EVEN . 2) (ODD . 3) (EVEN . 4)
     (ODD . 5) (EVEN . 6) (ODD . 7) (EVEN . 8)
      (ODD . 9) (EVEN . 10))
```


Comments on LOOP

- LOOP can be used functionally to compute one value from another

```
(LAMBDA (x)
    (LOOP FOR i IN x COLLECT (cons i nil)))
```

- Many uses of LOOP can be replaced by sequence functions such as FIND or the SERIES package

Documentation

```
(DEFUN add (x y)
   "adds 2 numbers"
   (+ x y))

(documentation 'add 'function)
→"adds 2 numbers"
```


Apropos

- returns all function names containing the given substring

```
(apropos 'add)→
SLOOP::*ADDITIONAL-COLLECTIONS*
⋮
Function COMPILER::ADD-FUNCTION-DECLARATION
⋮
Function CADDDR
⋮
Function ADD
```

Compilation GCL

```
(DEFUN add (x y) (+ x y))
(disassemble 'add)
→
static L1(){
  register object *base=vs_base;
  register object *sup=base+VM1; ...
  {object V1;  object V2;
   V1=(base[0]);
   V2=(base[1]);
   vs_top=sup; ...
   base[2]= number_plus((V1),(V2));
   vs_top=(vs_base=base+2)+1;
 return; }
}
```


Declarations GCL

- Types of arguments and return values can be declared to optimize compilation

```
(defun add (x y)
  (declare
    (fixnum x y)
    (optimize (speed 3) (safety 0) (debug 0)))
   (the fixnum (+ x y)))
```

Compilation with Declarations

```
(disassemble 'add) →
static L1(){ ...

   {int V1; int V2;
    V1=fix(base[0]);
    V2=fix(base[1]);
    ...
    base[2]= CMPmake_fixnum((V1)+(V2));
    ...
}}
```


Compilation: CLISP PPC

```
(DEFUN add (x y) (+ x y))
(DISASSEMBLE 'add)→

Disassembly of function ADD2
required arguments 0
optional arguments No
rest parameter No
keyword parameters
0      (LOAD&PUSH 2)
1      (LOAD&PUSH 2)
2      (CALLSR 2 54)    ; +
5      (SKIP&RET 3)
#<COMPILED-CLOSURE ADD>
```

GUI Development

- Many Lisps provide rich graphical interface libraries

```
(in-package "TK")
(tkconnect)
(button '.hello :text "Hello World"
                :command '(print "hi"))
==>.HELLO
(pack '.hello)
```