Robot Programming with Lisp

4. Functional Programming: Higher-order Functions, Currying, Map/Reduce

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- functions as *first class citizens*, as a result, higher-order functions (simplest analogy: callbacks);
- *lazy evaluations*, i.e. only execute a function call when its result is actually used;
- usage of lists as a main data structure; ....

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- **Racket**: 1994, latest release (8.6) in Aug 2022, focused on writing domain-specific programming languages

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Conclusion: functional programming becomes more and more popular.

Contents

Defining a Function

Signature

```
CL-USER>
(defun my-cool-function-name (arg-1 arg-2 arg-3 arg-4)
  "This function combines its 4 input arguments into a list
and returns it."
  (list arg-1 arg-2 arg-3 arg-4))
```

Optional Arguments

```
CL-USER> (defun optional-arguments (arg-1 arg-2 &optional arg-3 arg-4)
           (list arg-1 arg-2 arg-3 arg-4))
CL-USER> (optional-arguments 1 2 3 4)
(1 2 3 4)
CL-USER> (optional-arguments 1 2 3)
(1 2 3 NIL)
CL-USER> (optional-arguments 304)
invalid number of arguments: 1
```

Defining a Function [2]

Key Arguments

```
CL-USER>
(defun specific-optional (arg-1 arg-2 &key arg-3 arg-4)
  "This function demonstrates how to pass a value to
a specific optional argument."
  (list arg-1 arg-2 arg-3 arg-4))
SPECIFIC-OPTIONAL

CL-USER> (specific-optional 1 2 3 4)
unknown &KEY argument: 3

CL-USER> (specific-optional 1 2 :arg-4 4)
(1 2 NIL 4)
```

Defining a Function [3]

Unlimited Number of Arguments

```
CL-USER> (defun unlimited-args (arg-1 &rest args)
           (format t "Type of args is ~a.~%" (type-of args))
           (cons arg-1 args))
UNLIMITED-ARGS

CL-USER> (unlimited-args 1 2 3 4)
Type of args is CONS.
(1 2 3 4)

CL-USER> (unlimited-args 1)
Type of args is NULL.
(1)
```

Multiple Values

list vs. values

```
CL-USER> (defvar *some-list* (list 1 2 3))
*SOME-LIST*
CL-USER> *some-list*
(1 2 3)
CL-USER> (defvar *values?* (values 1 2 3))
*VALUES?*
CL-USER> *values?*
1
CL-USER> (values 1 2 3)
1
2
3
CL-USER> *
1
CL-USER> //
(1 2 3)
```

Multiple Values [2]

Returning Multiple Values!

```
CL-USER> (defvar *db* '((Anna 1987) (Bob 1899) (Charlie 1980)))
         (defun name-and-birth-year (id)
           (values (first (nth (- id 1) *db*))
                   (second (nth (- id 1) *db*))))
NAME-AND-BIRTH-YEAR

CL-USER> (name-and-birth-year 2)
BOB
1899

CL-USER> (multiple-value-bind (name year) (name-and-birth-year 2)
           (format t "~a was born in ~a.~%" name year))
BOB was born in 1899.
NIL
```

Function Designators

Similar to C pointers or Java references

Designator of a Function

```
CL-USER> (describe '+)
COMMON-LISP:+
  [symbol]
+ names a special variable:
+ names a compiled function:
CL-USER> #'+
CL-USER> (symbol-function '+)
#<FUNCTION +>
CL-USER> (describe #'+)
#<FUNCTION +>
  [compiled function]
Lambda-list: (&REST NUMBERS)
Declared type: (FUNCTION (&REST NUMBER) (VALUES NUMBER &OPTIONAL))
Derived type: (FUNCTION (&REST T) (VALUES NUMBER &OPTIONAL))
Documentation: ...
Source file: SYS:SRC;CODE;NUMBERS.LISP
```

Contents

Higher-order Functions

Function as Argument

```
CL-USER> (funcall #'+ 1 2 3)
CL-USER> (apply #'+ '(1 2 3))
6
CL-USER> (defun transform-1 (num) (/ 1.0 num))
TRANSFORM-1
CL-USER> (defun transform-2 (num) (sqrt num))
TRANSFORM-2
CL-USER> (defun print-transformed (a-number a-function)
           (format t "~a transformed with ~a becomes ~a.~%"
                   a-number a-function (funcall a-function a-number)))
PRINT-TRANSFORMED
CL-USER> (print-transformed 4 #'transform-1)
4 transformed with #<FUNCTION TRANSFORM-1> becomes 0.25.
CL-USER> (print-transformed 4 #'transform-2)
4 transformed with #<FUNCTION TRANSFORM-2> becomes 2.0.
CL-USER> (sort '(2 6 3 7 1 5) #'>)
(7 6 5 3 2 1)
```

Higher-order Functions [2]

Function as Return Value

```
CL-USER> (defun give-me-some-function ()
           (case (random 5)
             (0 #'+)
             (1 #'-)
             (2 #'*)
             (3 #'/)
             (4 #'values)))
GIVE-ME-SOME-FUNCTION

CL-USER> (give-me-some-function)
#<FUNCTION ->

CL-USER> (funcall (give-me-some-function) 10 5)
5

CL-USER> (funcall (give-me-some-function) 10 5)
2
```

Contents

Anonymous Functions

lambda

```
CL-USER> (sort '((1 2 3 4) (3 4) (6 3 6)) #'>)
The value (3 4) is not of type NUMBER.
CL-USER> (sort '((1 2 3 4) (3 4) (6 3 6)) #'> :key #'car)
((6 3 6) (3 4) (1 2 3 4))
CL-USER> (sort '((1 2 3 4) (3 4) (6 3 6))
               (lambda (x y)
                 (> (length x) (length y))))
((1 2 3 4) (6 3 6) (3 4))

CL-USER> (defun random-generator-a-to-b (a b)
           (lambda () (+ (random (- b a)) a)))
RANDOM-GENERATOR-A-TO-B
CL-USER> (random-generator-a-to-b 5 10)
#<CLOSURE (LAMBDA () :IN RANDOM-GENERATOR-A-TO-B) {100D31F90B}>
CL-USER> (funcall (random-generator-a-to-b 5 10))
9
```

Contents

Currying

Back to Generators

```
CL-USER> (let ((x^10-lambda (lambda (x) (expt x 10))))
           (dolist (elem '(2 3))
             (format t "~a^10 = ~a~%" elem (funcall x^10-lambda elem))))
2^10 = 1024
3^10 = 59049
;; The following only works with roslisp_repl. Otherwise do first:
;; (pushnew #p"/.../alexandria" asdf:*central-registry* :test #'equal)
CL-USER> (asdf:load-system :alexandria)
CL-USER> (dolist (elem '(2 3))
           (format t "10^~a = ~a~%"
                   elem (funcall (alexandria:curry #'expt 10) elem)))
10^2 = 100
10^3 = 1000
CL-USER> (dolist (elem '(2 3))
           (format t "~a^10 = ~a~%"
                   elem (funcall (alexandria:rcurry #'expt 10) elem)))
2^10 = 1024
3^10 = 59049
```

Contents

Mapping

Mapping in functional programming is the process of
applying a function to all members of a list, returning a list of results.

Supported in most functional programming languages and, in addition

- C++ (STL)
- Java 8+
- Python 1.0+
- C# 3.0+
- JavaScript 1.6+
- PHP 4.0+
- Ruby
- Mathematica
- Matlab
- Perl
- Prolog
- Smalltalk, ...

In some of the languages listed the implementation is limited and not elegant.

Mapping [2]

`mapcar` is the standard mapping function in Common Lisp.

mapcar *function list-1* `&rest` *more-lists* ⇒ *result-list*

Apply *function* to elements of *list-1*. Return list of *function* return values.

mapcar

```
CL-USER> (mapcar #'abs '(-2 6 -24 4.6 -0.2d0 -1/5))
(2 6 24 4.6 0.2d0 1/5)
CL-USER> (mapcar #'list '(1 2 3 4))
((1) (2) (3) (4))
CL-USER> (mapcar #'second '((1 2 3) (a b c) (10/3 20/3 30/3)))
?
CL-USER> (mapcar #'+ '(1 2 3 4 5) '(10 20 30 40))
?
CL-USER> (mapcar #'cons '(a b c) '(1 2 3))
?
CL-USER> (mapcar (lambda (x) (expt 10 x)) '(2 3 4))
?
```

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(2 6 24 4.6 0.2d0 1/5)
CL-USER> (mapcar #'list '(1 2 3 4))
((1) (2) (3) (4))
CL-USER> (mapcar #'second '((1 2 3) (a b c) (10/3 20/3 30/3)))
(2 B 20/3)
CL-USER> (mapcar #'+ '(1 2 3 4 5) '(10 20 30 40))
(11 22 33 44)
CL-USER> (mapcar #'cons '(a b c) '(1 2 3))
((A . 1) (B . 2) (C . 3))
CL-USER> (mapcar (lambda (x) (expt 10 x)) '(2 3 4))
(100 1000 10000)
```

Mapping [3]

`mapc` is mostly used for functions with side effects.

mapc *function list-1* `&rest` *more-lists* ⇒ *list-1*

mapc

```
CL-USER> (mapc #'set '(*a* *b* *c*) '(1 2 3))
(*A* *B* *C*)
CL-USER> *c*
3
CL-USER> (mapc #'format '(t t) '("hello, " "world~%"))
hello, world
(T T)
CL-USER> (mapc (alexandria:curry #'format t) '("hello, " "world~%"))
hello, world
("hello~%" "world~%")
CL-USER> (mapc (alexandria:curry #'format t "~a ") '(1 2 3 4))
1 2 3 4
(1 2 3 4)
CL-USER> (let (temp)
           (mapc (lambda (x) (push x temp)) '(1 2 3))
           temp)
```

Mapping [4]

`mapcan` combines the results using `nconc` instead of `list`.

mapcan *function list-1* `&rest` *more-lists* ⇒ *concatenated-results*

If the results are not lists, the consequences are undefined.

`nconc` vs `list`

```
CL-USER> (list '(1 2) nil '(3 45) '(4 8) nil)
((1 2) NIL (3 45) (4 8) NIL)
CL-USER> (nconc '(1 2) nil '(3 45) '(4 8) nil)
(1 2 3 45 4 8)
CL-USER> (nconc '(1 2) nil 3 '(45) '(4 8) nil)
; Evaluation aborted on #<TYPE-ERROR expected-type: LIST datum: 1>.
CL-USER> (let ((first-list (list 1 2 3))
               (second-list (list 4 5)))
           (values (nconc first-list second-list)
                   first-list
                   second-list))
        (1 2 3 4 5)
        (1 2 3 4 5)
        (4 5)
```

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mapcan

```
CL-USER> (mapcar #'list '(1 2 3))
((1) (2) (3))
CL-USER> (mapcan #'list '(1 2 3))
(1 2 3)
CL-USER> (mapcan #'alexandria:iota '(1 2 3))
(0 0 1 0 1 2)
CL-USER> (mapcan (lambda (x)
                   (when (numberp x)
                     (list x)))
                 '(4 n 1/3 ":)"))
(4 1/3)
```

Mapping [5]

`maplist`, `mapl` and `mapcon` operate on *sublists* of the input list.

maplist *function list-1* `&rest` *more-lists* ⇒ *result-list*

maplist

```
CL-USER> (mapcar #'identity '(1 2 3))
(1 2 3)
CL-USER> (maplist #'identity '(1 2 3))
((1 2 3) (2 3) (3))
CL-USER> (maplist (lambda (x)
                    (when (>= (length x) 2)
                      (- (second x) (first x))))
                  '(2 2 3 3 3 2 3 2 3 2 2 3))
                        . . .   .   .     .
                    . .       .   .   . .
                    (0 1 0 0 -1 1 -1 1 -1 0 1 NIL)
                       .       .   .     .
                      .   . .          .
                              .   .   .
CL-USER> (maplist (lambda (a-list) (apply #'* a-list)) '(4 3 2 1))
(24 6 2 1)
```

Mapping [5]

`maplist`, `mapl` and `mapcon` operate on *sublists* of the input list.

mapl *function list-1* `&rest` *more-lists* ⇒ *list-1*

mapcon *function list-1* `&rest` *more-lists* ⇒ *concatenated-results*

mapl

```
CL-USER> (let (temp)
           (mapl (lambda (x) (push x temp)) '(1 2 3))
           temp)
((3) (2 3) (1 2 3))
```

mapcon

```
CL-USER> (mapcon #'reverse '(4 3 2 1))
(1 2 3 4 1 2 3 1 2 1)
CL-USER> (mapcon #'identity '(1 2 3 4))
; Evaluation aborted on NIL.
```

Mapping [6]

`map` is a generalization of `mapcar` for *sequences* (lists and vectors).

map *result-type function first-sequence* `&rest` *more-sequences* ⇒ *result*

map

```
CL-USER> (mapcar #'+ #(1 2 3) #(10 20 30))
The value #(1 2 3) is not of type LIST.
CL-USER> (map 'vector #'+ #(1 2 3) #(10 20 30))
#(11 22 33)
CL-USER> (map 'list #'+ '(1 2 3) '(10 20 30))
(11 22 33)
CL-USER> (map 'list #'identity '(#\h #\e #\l #\l #\o))
(#\h #\e #\l #\l #\o)
CL-USER> (map 'string #'identity '(#\h #\e #\l #\l #\o))
"hello"
```

Reduction

reduce *function sequence* &key *key from-end start end initial-value* ⇒ *result*

Uses a binary operation, *function*, to combine the elements of *sequence*.

reduce

```
CL-USER>  (reduce (lambda (x y) (list x y)) '(1 2 3 4))
(((1 2) 3) 4)
CL-USER> (reduce (lambda (x y) (format t "~a ~a~%" x y)) '(1 2 3 4))
1 2
NIL 3
NIL 4
CL-USER> (reduce #'+ '()) ; ?
CL-USER> (reduce #'cons '(1 2 3 nil))
?
CL-USER> (reduce #'cons '(1 2 3) :from-end t :initial-value nil)
?
CL-USER> (reduce #'+ '((1 2) (3 4) (5 6))
                 :key #'first :start 1 :initial-value -10)
?
```

Reduction

reduce *function sequence* `&key` *key from-end start end initial-value* ⇒ *result*

Uses a binary operation, *function*, to combine the elements of *sequence*.

reduce

```
CL-USER>  (reduce (lambda (x y) (list x y)) '(1 2 3 4))
(((1 2) 3) 4)
CL-USER> (reduce (lambda (x y) (format t "~a ~a~%" x y)) '(1 2 3 4))
1 2
NIL 3
NIL 4
CL-USER> (reduce #'+ '()) ; ?
CL-USER> (reduce #'cons '(1 2 3 nil))
(((1 . 2) . 3))
CL-USER> (reduce #'cons '(1 2 3) :from-end t :initial-value nil)
(1 2 3)
CL-USER> (reduce #'+ '((1 2) (3 4) (5 6))
                 :key #'first :start 1 :initial-value -10)
-2 ; = -10 + 3 + 5
```

MapReduce

Google's *MapReduce* is a programming paradigm used mostly in huge databases for distributed processing. It was originally used for updating the index of the WWW in their search engine.

Currently supported by AWS, MongoDB, ...

Inspired by the `map` and `reduce` paradigms of functional programming.

`https://en.wikipedia.org/wiki/MapReduce`

MapReduce [2]
Example

Task: calculate at which time interval the number of travelers on the tram is the highest (intervals are "early morning", "late morning", ...)
Database: per interval hourly entries on number of travelers
(e.g. db_early_morning: 6:00 → Tram6 → 100, 7:00 → Tram8 → 120)
Map step: per DB, go through tram lines and sum up travelers:

- *DB1 early morning:* (Tram6 → 2000) (Tram8 → 1000) ...
- *DB6 late night:* (Tram6 → 200) (Tram4 → 500) ...

Reduce: calculate maximum of all databases for each tram line:
Tram6 → 3000 (late morning)
Tram8 → 1300 (early evening)
...

Contents

Guidelines

- Avoid global variables! Use them for constants.
- If your function generates side-effects, name it correspondingly (either `foo!` which is preferred, or `foof` as in `setf`, or `nfoo` as in `nconc`)
- Use `Ctrl-Alt-\` on a selected region to fix indentation
- Try to keep the brackets all together:

This looks weird in Lisp

```
(if condition
  do-this
  do-that
)
```

Links

- Alexandria documentation:
  http://common-lisp.net/project/alexandria/draft/alexandria.html

Info Summary

- NO LECTURE NEXT WEEK
- Assignment 4 points: 7 points
- Due **in two weeks**: 23.11, Wednesday, 23:59 German time
- Next class: 24.11, 14:15

Q & A

Thanks for your attention!