First-Class Functions in Racket

SOLUTIONS

CS251 Programming Languages
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First-Class Values

A value is **first-class** if it satisfies all of these properties:

- It can be named by a variable
- It can be passed as an argument to a function;
- It can be returned as the result of a function;
- It can be stored as an element in a data structure (e.g., a list);
- It can be created in any context.

Examples from Racket: numbers, boolean, strings, characters, lists, … and **functions**!

Functions can be Named

```
(define dbl (λ (x) (* 2 x)))
(define avg (λ (a b) (/ (+ a b) 2))))
(define pow
  (λ (base expt)
    (if (= expt 0)
        1
        (* base (pow base (- expt 1))))))
```

Recall syntactic sugar:

```
(define (dbl x) (* 2 x))
(define (avg a b) (/ (+ a b) 2))
(define (pow base expt) …)
```

Functions can be Passed as Arguments

```
(define app-3-5 (λ (f) (f 3 5))
(define sub2 (λ (x y) (- x y)))

({app-3-5} sub2)
⇒ (((λ (f) (f 3 5)) {sub2}) [varref]
⇒ {(((λ (f) (f 3 5)) (λ (x y) (- x y)))} [varref]
⇒ {(((λ (x y) (- x y)) 3 5)) [function call]
⇒ {(- 3 5)} [function call]
⇒ -2 [subtraction]
```
Functions can be Passed as Arguments

(define app-3-5 (λ (f) (f 3 5)))
(define sub2 (λ (x y) (- x y)))

{app-3-5 sub2) ⇒ ((λ (f) (f 3 5)) {sub2}) [varref]
⇒ {((λ (f) (f 3 5)) (λ (x y) (- x y)))} [varref]
⇒ {((λ (x y) (- x y)) 3 5)} [function call]
⇒ {- 3 5} [function call]
⇒ -2 [subtraction]

More Functions-as-Arguments Solutions

What are the values of the following?

(app-3-5 avg) ⇒* 4
(app-3-5 pow) ⇒* 243 ; 3^5
(app-3-5 (λ (a b) a)) ⇒* 3
(app-3-5 +) ⇒* 8

Functions can be Returned as Results from Other Functions

(define make-linear-function
  (λ (a b) ; a and b are numbers
    (λ (x) (+ (* a x) b))))
make-linear-function => (λ (a b) (λ (x) (+ (* a x) b)))

(define 4x+7 (make-linear-function 4 7))
4x+7 => (λ (x) (+ (* 4 x) 7))
; Note: This illustrates that functions are data structures! make-linear-function returns something similar to a Java object that "remembers" instance vars a and b!

(4x+7 0) ⇒* 7
(4x+7 1) ⇒* 11
(4x+7 2) ⇒* 15

(make-linear-function 6 1) ⇒* (λ (x) (+ (* 6 x) 1))

More Functions-as-Returned-Values Solutions

(define flip2
  (λ (binop)
    (λ (x y) (binop y x))))
flip2 => (λ (binop) (λ (x y) (binop y x)))

((flip2 sub2) 4 7) ⇒* 3
(app-3-5 (flip2 sub2)) ⇒* 2

((flip2 pow) 2 3) ⇒* 9 ; 3^2

(app-3-5 (flip2 pow)) ⇒* 125 ; 5^3

(define g ((flip2 make-linear-function) 4 7))
g => (λ (x) (+ (* 7 x) 4))
(list (g 0) (g 1) (g 2)) ⇒* ' (4 11 18)

((app-3-5 (flip2 make-linear-function)) 2) ⇒* 13
Functions can be Stored in Lists Solutions

(define funs (list sub2 avg pow app-3-5 make-linear-function flip2))

; funs is a list of 6 functions. In Racket, the printed representation of this list is:
'(#<procedure:sub2> #<procedure:avg> #<procedure:pow> #<procedure:app-3-5>
  #<procedure:make-linear-function> #<procedure:flip2>)

((first funs) 4 7) ⇒ -3
((fourth funs) (third funs)) ⇒ 243 ; 3^5
((fourth funs) ((sixth funs) (third funs))) ⇒ 125 ; 5^3
(((fourth funs) (fifth funs)) 2) ⇒ 11
(((fourth funs) ((sixth funs) (fifth funs))) 2) ⇒ 13

Python Functions are First-Class!

```python
def sub2 (x,y):
    return x - y
def app_3_5 (f):
    return f(3,5)
def make_linear_function(a, b):
    return lambda x: a*x + b
def flip2 (binop):
    return lambda x,y: binop(y,x)
```

In [2]: app_3_5(sub2)
Out[2]: -2

In [3]: app_3_5(flip2(sub2))
Out[3]: 2

In [4]: app_3_5(make_linear_function)(2)
Out[4]: 11

In [5]: app_3_5(flip2(make_linear_function))(2)
Out[5]: 13

JavaScript Functions are First-Class!

```javascript
function sub2 (x,y){
    return x - y;
}

function make_linear_function(a, b) {
    return function(x) {
        return a*x + b;
    };

function app_3_5 (f) {
    return f(3,5);
}

function flip2(binop) {
    return function(x,y) {
        return binop(y,x);
    };
}
```

> app_3_5(sub2)
< -2

> app_3_5(flip2(sub2))
< 2

> app_3_5(make_linear_function)(2)
< 11

> app_3_5(flip2(make_linear_function))(2)
< 13

Functions can be Created in Any Context

• In some languages (e.g., C) functions can be defined only at top-level. One function cannot be declared inside of another.

• Racket functions like make-linear-function and flip2 depend crucially on the ability to create one function inside of another function.
Summary (and Preview!)

Data and procedures and the values they amass,
Higher-order functions to combine and mix and match,
Objects with their local state, the messages they pass,
A property, a package, a control point for a catch —
In the Lambda Order they are all first-class.
One Thing to name them all, One Thing to define them,
One Thing to place them in environments and bind them,
In the Lambda Order they are all first-class.

Abstract for the Revised4 Report on the Algorithmic Language Scheme (R4RS), MIT Artificial Intelligence Lab Memo 848b, November 1991

Emblem for the Grand Recursive Order
of the Knights of the Lambda Calculus