Beginning OCaml II: Functions

CAS CS 320: Principles of Programming Languages

Thursday, January 25, 2024

Administrivia

- Homework 0 (not graded) is due today by 11:59 pm.
- Homework 1 (graded) is posted today and due on Thursday, Feb 1, by 11:59 pm.
- The office hours calendar has been updated with locations.

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Reading Assignment

- OCP Section 2.4: **Functions**
- OCP Section 2.6: **Printing**

function definitions (OCP 2.4.1)

```
(* increment function “inc” *)
let inc x = x + 1 ;;
(* increment function “inc1” *)
let inc1 x = x +. 1.0 ;;
```

Question 1: What is the type of “inc”?

Question 2: What is the type of “inc1”?

function definitions (OCP 2.4.1, 2.4.2)

```
(* increment function “inc” *)
let inc x = x + 1 ;;
(* increment function “inc1” *)
let inc1 x = x +. 1.0 ;;
```

Question 1: What is the type of “inc”?

Question 2: What is the type of “inc1”?

```
(* anonymous increment “(fun x -> x + 1)” applied to 3 *)
(fun x -> x + 1) 3 ;;
```

```
(* different way of defining named “inc” *)
let inc = fun x -> x + 1 ;;
```

function definitions (OCP 2.4.1)

```
(* squaring function “square” *)
let square x = x * x ;;
(* squaring function “square1” *)
let square1 x = x *. x ;;
```

Question 1: What is the type of “square”?

Question 2: What is the type of “square1”?

function definitions (OCP 2.4.1, 2.4.2)

```
(* squaring function “square” *)
let square x = x * x ;;
(* squaring function “square1” *)
let square1 x = x *. x ;;
```

Question 1: What is the type of “square”?

Question 2: What is the type of “square1”?

```
(* anonymous squaring “(fun x -> x * x)” applied to 3 *)
(fun x -> x * x) 3 ;;
```

```
(* different way of defining “square” *)
let square = fun x -> x * x ;;
```

recursive function definitions (OCP 2.4.1)

```
(* factorial function with if-then-else *)
(* requires: [n >= 0] *)
 let rec fact n =
   if n = 0 then 1 else n * fact (n – 1)
```

```
(* factorial function with types inserted *)
(* requires: [n >= 0] *)
 let rec fact1 (n : int): int =
   if n = 0 then 1 else n * fact1 (n – 1);;
```

```
(* print first 15 factorials 0! 1! … 15! *)
 let () =
  for n = 0 to 15 do Printf.printf "%d! = %d\n" n (fact n)
  done ;;
```

recursive function definitions (OCP 2.4.1)

```
(* factorial function with pattern matching *)        (* requires: [n >= 0] *)
let rec fact2 n =
  match n with
  | 0 -> 1
  | n -> n * fact2 (n – 1) ;;
```

recursive function definitions (OCP 2.4.1)

```
(* power function with if-then-else *)
(* requires: [y >= 0]. *)
let rec pow1 x y =
  if y = 0 then 1 else x * pow1 x (y – 1);;
```

```
(* power function with pattern matching *)
(* requires: [y >= 0]. *)
let rec pow2 x y =
  match y with
  | 0 -> 1
  | y -> x * pow2 x (y - 1) ;;
```

recursive function definitions (OCP 2.4.1)

```
(* GCD function with if-then-else *)
(* requires: [n >= 0 && m >= 0] ??? *)
let rec gcd1 n m =
   if m = 0 then n else gcd1 m (n mod m);;
```

```
(* GCD function with pattern matching *)
(* requires: [n >= 0 && m >= 0] ??? *)
let rec gcd2 n m =
   match m with
   | 0 -> n
   | m -> gcd2 m (n mod m) ;;
```

mutually recursive function definitions – using the "and" keyword (OCP 2.4.1)

```
(* [even n] is whether [n] is even.
   Requires: [n >= 0]. *)
let rec even (n : int) : bool =
    n = 0 || odd (n - 1)

(* [odd n] is whether [n] is odd.
   Requires: [n >= 0]. *)
  and odd (n : int) : bool =
   n <> 0 && even (n - 1);;
```

mutually recursive function definitions – using the “and” keyword (OCP 2.4.1)

```
let rec first x = match x with
  | 1 -> 1
  | x -> second (x mod 10)
  and second x = first (x + 1);;
```

- **Question 1:**

  What are the types of “first” and “second”?

- **Question 2:**

  What do “first” and “second” compute?

<u>function application</u> (OCP 2.4.3)

Question: Which expressions are correctly parenthesized?

1. gcd inc 5 square 4
2. ((((gcd inc) 5) square) 4)
3. (gcd (inc (5 (square 4))))
4. (gcd (inc 5) (square 4))
5. gcd (inc 5) square 4
6. gcd inc 5 (square 4)
7. gcd (inc 5) (square 4)

function application (OCP 2.4.3)

Question: Which expressions are correctly parenthesized?

1. gcd inc 5 square 4 **NO**
2. ((((gcd inc) 5) square) 4) **NO**
3. (gcd (inc (5 (square 4)))) **NO**
4. (gcd (inc 5) (square 4)) **YES**
5. gcd (inc 5) square 4 **NO**
6. gcd inc 5 (square 4) **NO**
7. gcd (inc 5) (square 4) **YES**

function application (OCP 2.4.3)

Question: Which expressions are correctly parenthesized?

1. gcd inc 5 square 4 **NO**
2. ((((gcd inc) 5) square) 4) **NO**
3. (gcd (inc (5 (square 4)))) **NO**
4. (gcd (inc 5) (square 4)) **YES**
5. gcd (inc 5) square 4 **NO**
6. gcd inc 5 (square 4) **NO**
7. gcd (inc 5) (square 4) **YES**

more generally:

e_0 e_1 ... e_n means (...(e_0 e_1)... e_n) provided (e_i : t -> u) and (e_{i+1} : t)

type-checking function application

```
(gcd : int -> (int -> int))
  (inc : int -> int)
    (5 : int)
      (square : int -> int)
        (4 : int)
```

type-checking function application

```
(gcd : int -> (int -> int))
  (inc : int -> int)
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(gcd : int -> (int -> int))
  ((inc : int -> int)
    (5 : int) : int)
      ((square : int -> int)
        (4 : int) : int)
```

type-checking function application

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(gcd : int -> (int -> int))
  (inc : int -> int)
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(gcd : int -> (int -> int))
  ((inc : int -> int)
    (5 : int) : int)
      ((square : int -> int)
        (4 : int) : int)
```

```
((gcd : int -> (int -> int))
  ((inc : int -> int)
    (5 : int) : int) : (int -> int))
      ((square : int -> int)
              (4 : int) : int)
```

pipelining (OCP 2.4.4)

instead of (inc (square (inc 4));; we can **pipeline** the function applications:

4 |> inc |> square |> inc ;;

more generally: e_1 |> e_2 means (e_2 e_1) provided that (e_1 : t) and (e_2 : t -> u)

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pipelining binary (or non-unary) functions, such as gcd, is a little cumbersome …

Question: how to pipeline gcd (inc 5) (square 4) ;;?

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Question: how to pipeline gcd (inc 5) (square 4) ;;?

Answer: 4 |> square |> **(**5 |> inc |> gcd**)** ;;

polymorphic functions (OCP 2.4.5)

the identity function id is **polymorphic**:

```
let id1 x = x ;;

let id2 = fun x -> x ;;
```

in both cases, the type is `val id : 'a -> 'a = <fun>` .

polymorphic functions (OCP 2.4.5)

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```

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We can enforce a specific type for the identity, e.g.

```
let id3 (x : int) = x ;;

let id4 (x : bool) = x ;;

let id5 (x : (int -> bool) -> (int -> bool)) = x ;;

let id6 (x : ('a -> 'b) - > ('a -> 'b) = x ;;
```

labeled and optional arguments (OCP 2.4.6)

```
(* inserting labels ~lbl1 and ~lbl2, and types *)
let foo1 ~lbl1:(x : int) ~lbl2:(y : int) = x / y ;;
(* same as preceding after omitting the type *)
let foo2 ~lbl1: x ~lbl2: y = x / y ;;
```

the type of foo1 and foo2 is `lbl1:int -> lbl2:int -> int`

labeled and optional arguments (OCP 2.4.6)

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```

the type of foo1 and foo2 is `lbl1:int -> lbl2:int -> int`

a little more confusing ...

```
(* labels ~x and ~y have same names as args x and y!!! *)
let foo3 ~x:(x : int) ~y:(y : int) = x / y ;;
```

the type of foo3 is `x:int -> y:int -> int`

labeled and optional arguments (OCP 2.4.6)

```
(* inserting labels ~lbl1 and ~lbl2, and types *)
let foo1 ~lbl1:(x : int) ~lbl2:(y : int) = x / y ;;
(* same as preceding after omitting the type *)
let foo2 ~lbl1: x ~lbl2: y = x / y ;;
```

the type of foo1 and foo2 is lbl1:int -> lbl2:int -> int

a little more confusing ...

```
(* labels ~x and ~y have same names as args x and y!!! *)
let foo3 ~x:(x : int) ~y:(y : int) = x / y ;;
```

the type of foo3 is x:int -> y:int -> int

Question: what is the point of labels?

Answer: we can permute the argument, e.g. we can write foo3 ~y:6 ~x:40 instead of foo3 40 6 .

partial application (OCP 2.4.7)

Once more, the power function:

```
(* power function with if-then-else *)
(* requires: [y >= 0]. *)
let rec pow x y =
  if y = 0 then 1 else x * pow x (y – 1);;
```

the interpreter returns the following type :

```
val pow : int -> int -> int = <fun>
```

implicitly “->” associates to the right, i.e. the type is:

```
int -> (int -> int)
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partial application (OCP 2.4.7)

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```
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```

we can apply "pow" to one argument at a time as in:

```
let power_of_2 = pow 2 ;;
val power_of_2 : int -> int = <fun>
```

function associativity (OCP 2.4.8)

a function with more than one argument, e.g.:

```
let f x_1 x_2 x_3 x_4 = e
```

is semantically equivalent to

```
let f =
 fun x_1 ->
  (fun x_2 ->
    (fun x_3 ->
      (fun x_4 -> e)))
```

the type of function f is of the form:

```
t_1 -> (t_2 -> (t_3 -> (t_4 -> u)))
```

since function types are *right associative*, the type of f is:

```
t_1 -> t_2 -> t_3 -> t_4 -> u
```

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