Programming Languages and Techniques (CIS120)

Lecture 12

February 10th 2016

Finite Maps; Partiality and Option Types

Announcements

- Dr. Zdancewic will hold class on Friday
  - bring your clickers
- Midterm 1
  - Next Tuesday evening, **6:15PM**
  - Register *by Sunday* if you need the make-up exam
  - Covers lecture material through TODAY (Ch. 10)
  - Review materials (old exams) on course website
  - May bring 1 single-sided handwritten "cheat sheet" to the exam, make sure your name is on it

Finite Map *signature*

```
module type MAP = sig

  type ('k,'v) map

  val empty   : ('k,'v) map
  val add     : 'k -> 'v -> ('k,'v) map -> ('k,'v) map
  val remove  : 'k       -> ('k,'v) map -> ('k,'v) map
  val mem     : 'k -> ('k,'v) map -> bool
  val get     : 'k -> ('k,'v) map -> 'v
  val entries : ('k,'v) map -> ('k * 'v) list
  val equals  : ('k,'v) map -> ('k,'v) map -> bool

end
```

.ml and .mli files

- You’ve already been using signatures and modules in OCaml.

- A series of type and `val` declarations stored in a file `foo.mli` is considered as defining a signature FOO
- A series of top-level definitions stored in a file `foo.ml` is considered as defining a module Foo

foo.mli

```
type t
val z : t
val f : t -> int
```

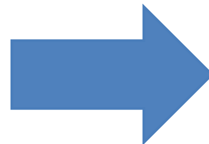
foo.ml

```
type t = int
let z : t = 0
let f (x:t) : int =
  x + 1
```

test.ml

```
;; open Foo
;; print_int
      (Foo.f Foo.z)
```

Files



```
module type FOO = sig
  type t
  val z : t
  val f : t -> int
end

module Foo : FOO = struct
  type t = int
  let z : t = 0
  let f (x:t) : int =
    x + 1
end

module Test = struct
  ;; open Foo
  ;; print_int
        (Foo.f Foo.z)
end
```

Summary: Abstract Types

- Different programming languages have different ways of letting you define abstract types

- At a minimum, this means providing:
  - A way to specify (write down) an interface
  - A means of hiding implementation details (*encapsulation*)

- In OCaml:
  - Interfaces are specified using a *signature* or *interface*
  - Encapsulation is achieved because the interface can *omit* information
    - type definitions
    - names and types of auxiliary functions
  - Clients *cannot* mention values or types not named in the interface

Which of these is a function that calculates the maximum value in a (generic) list:

1.

```
let rec list_max (l:'a list) : ’a =
  begin match l with
  | [] -> []
  | h :: t -> max h (list_max t)
  end
```

2.

```
let rec list_max (l:'a list) : ’a =
  fold max 0 l
```

3.

```
let rec list_max (l:’a list) : ‘a =
  begin match l with
  | h :: t -> max h (list_max t)
  end
```

4. None of the above

Answer: 4

Quiz answer

- list_max isn't defined for the empty list!

```
let rec list_max (l:'a list) : 'a =
  begin match l with
    | [] -> failwith "empty list"
    | [h] -> h
    | h::t -> max h (list_max  t)
  end
```

```
(* INCORRECT!  *)
let list_max (l:'a list) : 'a =
  begin match l with
    | [] -> failwith "empty list"
    | h::t -> fold max h t
  end
```

Client of list_max

```
(* string_of_max calls list_max *)
let string_of_max (x:int list) : string =
  string_of_int (list_max x)
```

- Oops! `string_of_max` will fail if given `[]`
- Not so easy to debug if `string_of_max` is written by one person and `list_max` is written by another.
- Interface of list_max is not very informative

```
val list_max : int list -> int
```

Dealing with Partiality*

*A function is said to be *partial* if it is not defined for all inputs.

Solutions to Partiality: Option 1

- Abort the program: `failwith "an error message"`
  - Whenever it is called, `failwith` halts the program and reports the error message it is given.
- This solution is appropriate whenever you *know* that a certain case is impossible
  - The compiler isn't smart enough to figure out that the case is impossible…
  - Often happens when there is an invariant on a datastructure
  - `failwith` is also useful to "stub out" unimplemented parts of your program.

Solutions to Partiality: Option 2

- Return a *default or error value*
  - e.g. define `list_max []` to be `-1`
  - Error codes used often in C programs
  - `null` used often in Java
- But…
  - What if -1 (or whatever default you choose) really *is* the maximum value?
  - Can lead to many bugs if the default or error value isn't handled properly by the callers.
  - *IMPOSSIBLE* to implement generically!
    - There is no way to generically create a sensible default value for every possible type
    - Sir Tony Hoare, Turing Award winner and inventor of `null` calls it his "*billion dollar mistake*"!
- Defaults should be avoided if possible

Optional values

Solutions to Partiality: Option 3

Option Types

- Define a generic datatype of *optional values*:

```
type 'a option =
   | None
   | Some of 'a
```

- A “partial” function returns an option

```
let list_max (l:list) : int option = …
```

- Contrast this with “null”, a “legal” return value of any type
  - caller can accidentally forget to check whether null was used; results in NullPointerExceptions or crashes

Example: list_max

- A function that returns the maximum value of a list as an option (None if the list is empty)

```
let list_max (l:'a list) : 'a option =
  begin match l with
    | [] -> None
    | x::tl -> Some (fold max x tl)
  end
```

Revised client of list_max

```
(* string_of_max calls list_max *)
let string_of_max (l:int list) : string =
  begin match (list_max l) with
  | None -> “no maximum”
  | Some m -> string_of_int m
  end
```

- `string_of_max` will never fail

- The type of list_max makes it explicit that a client must check for partiality.

```
val list_max : int list -> int option
```

What is the type of this function?

```
let head (x: ______) : ______  =
  begin match x with
  | [] -> None
  | h :: t -> Some h
  end
```

1. ‘a list -> ‘a

2. ‘a list -> ‘a list

3. ‘a list -> ‘b option

4. ‘a list -> ‘a option

4. None of the above

Answer: 4

What is the value of this expression?

```
let head (x: 'a list) : 'a option  =
   begin match x with
   | [] -> None
   | h :: t -> Some  h
   end in

head [[1]]
```

1. 1
2. Some 1
3. [1]
4. Some [1]
5. None of the above

Answer: 4

What is the value of this expression?

```
let head (x: ‘a list) : ‘a option  =
   begin match x with
   | [] -> None
   | h :: t -> Some h
   end in

[ head [1];  head [] ]
```

1. [1 ; 0]
2. 1
3. [Some 1; None]
4. [None; None]
5. None of the above

Answer: 3