CMSC 330: Organization of Programming Languages

OCaml Data Types

OCaml Data

- So far, we've seen the following kinds of data
  - Basic types (int, float, char, string)
  - Lists
    - One kind of data structure
    - A list is either [ ] or h::t, deconstructed with pattern matching
  - Tuples and Records
    - Let you collect data together in fixed-size pieces
  - Functions

- How can we build other data structures?
  - Building everything from lists and tuples is awkward

User Defined Types

- **`type`** can be used to create new names for types

- Like **`typedef`** in C – a name might be more useful for communicating intent than just the type structure

User Defined Types

```
# type mylist = int*(int list);;
type mylist = int * int list

# let empty:mylist = (0,[]);;
val empty : mylist = (0, [])

# let add x ((n,xs):mylist):mylist = (n+1,x::xs);;
val add : int -> mylist -> mylist = <fun>

# let length ((n,_):mylist) = n;;
val length : mylist -> int = <fun>

# let x = add 1 (add 2 empty);;
val x : mylist = (2, [1; 2])
```

Annotation required to tell type inference you want `mylist`, not `int*int list`

(User-Defined) Variants

```
type coin = Heads | Tails

let flip x =
  match x with
  | Heads -> Tails
  | Tails -> Heads

let rec count_heads x =
  match x with
  | [] -> 0
  | (Heads::x') -> 1 + count_heads x'
  | (_::x') -> count_heads x'
```

In simplest form: Like a C **`enum`**

Basic pattern matching resembles C **`switch`**

Combined list and variant patterns possible

Constructing and Destructing Variants

- Syntax
  - `type t = C1 | … | Cn`
  - the ***Ci*** are called constructors
    - Must begin with a capital letter
- Evaluation
  - A constructor ***Ci*** is already a value
  - Destructing a value ***v*** of type ***t*** is done by pattern matching on ***v*** ; the patterns are the constructors ***Ci***
- Type Checking
  - ***Ci*** : ***t*** (for each ***Ci*** in ***t***'s definition)

Data Types: Variants with Data

- We can define variants that “carry data” too
  - Not just a constructor, but a constructor *with values*

```
type shape =
  | Rect of float * float (* width*length *)
  | Circle of float       (* radius *)
```

- **`Rect`** and **`Circle`** are constructors, so a **`shape`** is either
  - **`Rect(`*`w`*`,`*`l`*`)`** for any floats ***`w`*** and ***`l`***, or
  - **`Circle`** ***`r`*** for any float ***`r`***

Data Types: Pattern Matching

```
let area s =
  match s with
    | Rect (w, l) -> w *. l
    | Circle r -> r  *. r *. 3.14
;;
area (Rect (3.0, 4.0));; (* 12.0  *)
area (Circle 3.0);;      (* 28.26 *)
```

- Use pattern matching to deconstruct values
  - Can bind pattern values to data parts

Data types are *aka* algebraic data types and tagged unions

Data Types: Pattern Matching

```
type shape =
  | Rect of float * float (* width*length *)
  | Circle of float       (* radius *)

let lst = [Rect (3.0, 4.0) ; Circle 3.0]
```

- What's the type of `lst`?
  - `shape list`
- What's the type of `lst`'s first element?
  - `shape`

Quiz 1

```
type foo = (int * (string list)) list
```

Which one of the following could match type **foo**?

A. `[(3, "foo", "bar")]`
B. `[(7, ["foo", "bar"])]`
C. `[(5, ["foo"; "bar"])]`
D. `[(9, [("foo", "bar")])]`

Quiz 1

```
type foo = (int * (string list)) list
```

Which one of the following could match type **`foo`**?

A. `[(3, "foo", "bar")]`
B. `[(7, ["foo", "bar"])]`
C. `[(5, ["foo"; "bar"])]`
D. `[(9, [("foo", "bar")])]`

Quiz 2: What does this evaluate to?

```
type num = Int of int | Float of float;;

let aux a =
  match a with
   | Int i -> float_of_int i
   | Float j -> j
;;

aux (Int 2);;
```

A. `4.0`

B. `2.0`

C. `2`

D. Type Error

Quiz 2: What does this evaluate to?

```
type num = Int of int | Float of float;;

let aux a =
  match a with
   | Int i -> float_of_int i
   | Float j -> j
;;

aux (Int 2);;
```

A. `4.0`

B. `2.0`

C. `2`

D. Type Error

Variation: Shapes in Java

Compare this to OCaml

```
public interface Shape {
    public double area();
}
```

```
class Rect implements Shape {
  private double width, length;

  Rect (double w, double l) {
    this.width = w;
    this.length = l;
  }

  double area() {
    return width * length;
  }
}
```

```
class Circle implements Shape {
  private double rad;

  Circle (double r) {
    this.rad = r;
  }


  double area() {
    return rad * rad * 3.14159;
  }
}
```

Option Type

```
type optional_int =
 | None
 | Some of int

let divide x y =
  if y != 0 then Some (x/y)
  else None

let string_of_opt o =
  match o with
   | Some i -> string_of_int i
   | None -> "nothing"
```

```
let p = divide 1 0;;
print_string
   (string_of_opt p);;
(* prints "nothing" *)

let q = divide 1 1;;
print_string
   (string_of_opt q);;
(* prints "1" *)
```

- Comparing to Java: **`None`** is like **`null`**, while **`Some`** *i* is like an **`Integer(`*****i*****`)`** object

Polymorphic Option Type

- A Polymorphic version of **`option`** type can work with *any kind of data*
  - As int option, char option, etc...

Polymorphic parameter: like **`Option<T>`** in Java

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

```
let opthd l =
  match l with
  | [] -> None
  | x::_ -> Some x
```

In fact, this option type is built into OCaml

```
let p = opthd [];;     (* p = None *)
let q = opthd [1;2];;  (* q = Some 1 *)
let r = opthd ["a"];;  (* r = Some "a" *)
```

Quiz 3: What does this evaluate to?

```
let foo f = match f with
   | None -> 42.0
   | Some n -> n +. 42.0
;;
foo 3.3;;
```

A. `45.3`
B. `42.0`
C. `Some 45.3`
D. Error

Quiz 3: What does this evaluate to?

```
let foo f = match f with
   | None -> 42.0
   | Some n -> n +. 42.0
;;
~~foo 3.3~~;;   foo (Some 3.3)
```

A. `45.3`

B. `42.0`

C. `Some 45.3`

D. **Error**

Recursive Data Types

- We can build up lists with recursive variant types

```
type 'a mylist =
  | Nil
  | Cons of 'a * 'a mylist

let rec len x = match x with
  | Nil -> 0
  | Cons (_, t) -> 1 + (len t)

len (Cons (10, Cons (20, Cons (30, Nil))))
(* evaluates to 3 *)
```

- Won't have nice [1; 2; 3] syntax for this kind of list

Recursive Data Types

- We can build up lists with recursive variant types

```
type 'a bt =
  | Leaf
  | Node of 'a * 'a bt * 'a bt

let rec height t = match t with
  | Leaf -> 0
  | Node (_, l, r) ->
    1 + (max (height l) (height r))

height (Node (10,
              Node (2, Leaf, Leaf),
              Leaf))
(* evaluates to 2 *)
```

Variants (full definition)

- Syntax
  - `type t = C1 [of t1] | … | Cn [of tn]`
  - the *Ci* are called constructors
    - Must begin with a capital letter; may include associated data - notated with brackets [] to indicate it's optional
- Evaluation
  - A constructor *Ci* is a value if it has no assoc. data
    - *Ci vi* is a value if it does
  - Destructing a value of type *t* is by pattern matching
    - patterns are constructors *Ci* with data components, if any
- Type Checking
  - *Ci* [*vi*] : *t* [if *vi* has type *ti*]

OCaml Exceptions

```
exception My_exception of int
let f n =
  if n > 0 then
    raise (My_exception n)
  else
    raise (Failure "foo")
let bar n =
  try
    f n
  with My_exception n ->
      Printf.printf "Caught %d\n" n
    | Failure s ->
      Printf.printf "Caught %s\n" s
```

OCaml Exceptions: Details

- Exceptions are declared with exception
  - They may appear in the signature as well
- Exceptions may take arguments
  - Just like type constructors
  - May also have no arguments
- Catch exceptions with try...with...
  - Pattern-matching can be used in with
  - If an exception is uncaught
    - Current function exits immediately
    - Control transfers up the call chain
    - Until the exception is caught, or until it reaches the top level

OCaml Exceptions: Useful Examples

- `failwith s`: Raises exception Failure s (s is a string).
- `Not_found`: Exception raised by library functions if the object does not exist
- `invalid_arg s`: Raises exception Invalid_argument s

```
let div x y =
  if y = 0 then failwith "div by 0" else x/y;;

let lst =[(1,"alice");(2,"bob");(3,"cat")];;
let lookup key lst =
  try
    List.assoc key lst
  with
    Not_found -> "key does not exist"
```