CMSC330

Data types, exceptions, and modules

Last time

- Ocaml closures and currying

This time

- Finishing up Ocaml
  - Data types
  - Exceptions
  - Modules

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
    - 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

Data types

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

- `Rect` and `Circle` are type constructors
  - Here a `shape` is either a `Rect` or a `Circle`

Data Types (cont.)


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

area (Rect (3.0, 4.0))
area (Circle 3.0)
```

- Use pattern matching to deconstruct values
  - **s** is a **shape**
  - Do different things for **s** depending on its constructor

Data Types (cont.)

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

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

- What's the type of `l`?

  `shape list`

- What's the type of `l`'s first element?

  `shape`

Data Types Constructor

- Constructors must begin with uppercase letter
- The arity of a constructor
  - Is the number of arguments it takes
  - A constructor with no arguments is nullary

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

- Example
  - Arity of `None` = 0
  - Arity of `Some` = 1

Polymorphic Data Types


```
type optional_int =
    None
  | Some of int
let add_with_default a = function
      None -> a + 42
    | Some n -> a + n
add_with_default 3 None          (* 45 *)
add_with_default 3 (Some 4)      (* 7  *)
```

- This option type can work with any kind of data
  - In fact, this option type is built into OCaml

Recursive Data Types

- We can build up lists this way

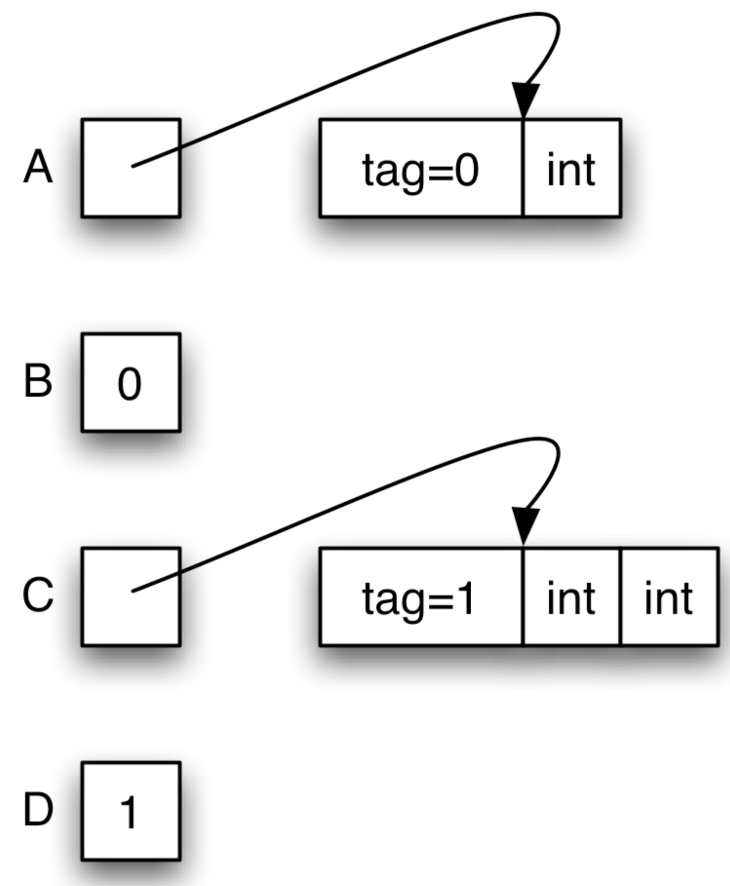
```
type 'a list =
   Nil
 | Cons of 'a * 'a list

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

len (Cons (10, Cons (20, Cons (30, Nil))))
```

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

Data Type Representations

- Values in a data type are stored
  1. Directly as integers
  2. As pointers to blocks in the heap

```
type t =
  A of int
| B
| C of int * int
| D
```



Exercise: A Binary Tree Data Type

- Write type `bin_tree` for binary trees over `int`
  - Trees should be ordered (binary search tree)

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 (cont.)

- Exceptions are declared with **`exception`**
- Exceptions may take arguments
  - Just like type constructors
  - May also be nullary
- 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 reaches the top level

Ocaml exceptions (cont.)

- Exceptions may be thrown by I/O statements
  - Common way to detect end of file
  - Need to decide how to handle exception
- Example

```
try
  (input_char stdin)    (* reads 1 char *)
with End_of_file -> 0   (* return 0?    *)

try
  read_line ()          (* reads 1 line *)
with End_of_file -> ""  (* return ""?   *)
```

Modules

- So far, most everything we've defined
  - Has been at the "top-level" of OCaml
  - This is not good software engineering practice
- A better idea
  - Use modules to group together associated
    - Types, functions, and data
  - Avoid polluting the top-level with unnecessary stuff
- For lots of sample modules
  - See the OCaml standard library

Modularity and Abstraction

- Another reason for creating a module
  - So we can hide details
  - Example
    - Build a binary tree module
    - Hide exact representation of binary trees
  - This is also good software engineering practice
    - Prevents clients from relying on details that may change
    - Hides unimportant information
    - Promotes local understanding (clients can't inject arbitrary data structures, only ones our functions create)

Modularity

- Definition
  - Extent to which a computer program is composed of separate parts
  - Higher degree of modularity is better
- Modular programming
  - Programming techniques that increase modularity
    - Interface vs. implementation
- Modular programming languages
  - Explicit support for modules
  - Ada, Fortran, ML, Modula-2, Python, Ruby, OCaml

Creating a module in Ocaml

```
module Shapes =
  struct
    type shape =
       Rect of float * float (* wid*len *)
     | Circle of float       (* radius  *)

    let area = function
       Rect (w, l) -> w *. l
     | Circle r -> r  *. r *. 3.14

    let unit_circle = Circle 1.0
  end;;
```

Creating a module in Ocaml (cont.)

```
module Shapes =
  struct
    type shape = …
    let area = …
    let unit_circle = …
  end;;
unit_circle;;    (* not defined *)
Shapes.unit_circle;;
Shapes.area (Shapes.Rect (3.0, 4.0));;
open Shapes;; (* import names
                 into curr scope *)
unit_circle;;    (* now defined *)
```

Module Signatures

Entry in signature

Supply function types

```
module type FOO =
   sig
     val add : int -> int -> int
   end;;
module Foo : FOO =
   struct
     let add x y = x + y
     let mult x y = x * y
   end;;
Foo.add 3 4;;      (* OK *)
Foo.mult 3 4;;     (* not accessible *)
```

Give type to module

Module signatures (cont.)

- Convention
  - Signatures to be all capital letters
  - This isn't a strict requirement, though
- Items can be omitted from a module signature
  - This provides the ability to hide values
- The default signature for a module hides nothing
  - You'll notice this is what OCaml gives you if you just type in a module with no signature at the top-level

Abstract Types in signatures

```
module type SHAPES =
  sig
    type shape
    val area : shape -> float
    val unit_circle : shape
    val make_circle : float -> shape
    val make_rect : float -> float -> shape
end;;

module Shapes : SHAPES =
  struct
    ...
    let make_circle r = Circle r
    let make_rect x y = Rect (x, y)
  end
```

- Now definition of `shape` is hidden

Abstract Types in signatures (cont.)

```
# Shapes.unit_circle
- : Shapes.shape = <abstr>  (* OCaml won't show impl *)
# Shapes.Circle 1.0
Unbound Constructor Shapes.Circle
# Shapes.area (Shapes.make_circle 3.0)
- : float = 29.5788
# open Shapes;;
# (* doesn't make anything abstract accessible *)
```

- How does this compare to modularity in...
  - C?
  - C++?
  - Java?

.ml and .mli files

- Put the signature in a foo.mli file, the struct in a foo.ml file
  - Use the same names
  - Omit the `sig...end` and `struct...end` parts
  - The OCaml compiler will make a Foo module from these

Example – Ocaml module signatures

shapes.mli

```
type shape
val area : shape -> float
val unit_circle : shape
val make_circle : float -> shape
val make_rect : float -> float -> shape
```

shapes.ml

```
type shape =
  Rect of ...
...
let make_circle r = Circle r
let make_rect x y = Rect (x, y)
```

```
% ocamlc shapes.mli   # produces shapes.cmi
% ocamlc shapes.ml    # produces shapes.cmo
ocaml
# #load "shapes.cmo"  (* load Shapes module *)
```

Module in Java

- Java classes are like modules
  - Provides implementations for a group of functions
  - But classes can also
    - Instantiate objects
    - Inherit attributes from other classes
- Java interfaces are like module signatures
  - Defines a group of functions that may be used
  - Implementation is hidden

Modules in C

- .c files are like modules
  - Provides implementations for a group of functions
- .h files are like module signatures
  - Defines a group of functions that may be used
  - Implementation is hidden
- Usage is not enforced by C language
  - Can put C code in .h file

So Far, Only Functional Programming

- We haven't given you any way so far to change something in memory
  - All you can do is create new values from old
- This actually makes programming easier !
  - Don't care whether data is shared in memory
    - Aliasing is irrelevant
  - Provides strong support for compositional reasoning and abstraction
    - Example: Calling a function f with argument x always produces the same result
  - But could take (much) more memory & time to execute

Imperative Ocaml

- There are three basic operations on memory

1) `ref : 'a -> 'a ref`
   - Allocate an updatable reference

2) `! : 'a ref -> 'a`
   - Read the value stored in reference

3) `:= : 'a ref -> 'a -> unit`
   - Write to a reference

```
let x = ref 3  (* x : int ref *)
let y = !x
x := 4
```

Comparison to L- and R-values

- Recall that in C/C++/Java, there's a strong distinction between l- and r-values
  - An r-value refers to just a value, like an integer
  - An l-value refers to a location that can be written

l-value

```
y = x;
```

r-value

- A variable's meaning depends on where it appears
  - On the right-hand side, it's an r-value, and it refers to the contents of the variable
  - On the left-hand side of an assignment, it's an l-value, and it refers to the location the variable is stored in

L-Values and R-Values in C (cont.)

```
int x;
int y;

x = 3;

y = x;

3 = x;
```

Store 3 in location x

Read contents of x and store in location y

Makes no sense

Comparison to Ocaml

```c
int x;  C
Int y;

x = 3;

y = x;

3 = x;
```

```ocaml
let x = ref 0;;                              OCaml
let y = ref 0;;

x := 3;;   (* x : int ref *)

y := (!x);;

3 := x;;   (* 3 : int; error *)
```

- In OCaml, an updatable location and the contents of the location have different types
  - The location has a `ref` type

Capturing a ref in a Closure

- We can use **ref** to make things like counters that produce a fresh number "everywhere"

```
let next =
  let count = ref 0 in
    function () ->
      let temp = !count in
        count := (!count) + 1;
        temp;;
# next ();;
- : int = 0
# next ();;
- : int = 1
```

Semicolon Revisited; Side Effects

- Now that we can update memory, we have a real use for ; and ( ) : unit
  - e1; e2 means evaluate e1, throw away the result, and then evaluate e2, and return the value of e2
  - () means “no interesting result here”
  - It’s only interesting to throw away values or use ()
    - If computation does something besides return a result
- A side effect is a visible state change
  - Modifying memory
  - Printing to output
  - Writing to disk

Grouping with begin...end

- If you're not sure about the scoping rules, use **`begin`**...**`end`** to group together statements with semicolons

```
let x = ref 0

let f () =
  begin
    print_string "hello";
    x := (!x) + 1
  end
```

Trade-off of side effects

- Side effects are absolutely necessary
  - That's usually why we run software!
  - We want something to happen that we can observe

- But…they also make reasoning harder
  - Order of evaluation now matters
  - Calling the same function in different places may produce different results
  - Aliasing is an issue
    - If we call a function with refs r1 and r2, it might do strange things if r1 and r2 are aliased

Ocaml language choices

- Implicit or explicit declarations?
  - Explicit – variables must be introduced with let before use
  - But you don’t need to specify type of variable
- Static or dynamic types?
  - Static – but without type declarations
  - OCaml does type inference to figure out types for you
    - Advantage – less work to write programs
    - Disadvantages – easier to make mistakes, harder to find errors

Summary

- Ocaml
  - Data types
  - Exceptions
  - Modules
- Tomorrow
  - Midterm review
  - Bring questions