CMSC 330: Organization of Programming Languages

Functional Programming with OCaml

Reminders / Announcements

- Project 2 due Oct. 12

Review

- function declaration
- types
- lists
- matching

Example

```
    match e with p1 -> e1 | ... | pn -> en

let is_empty l = match l with
     [] -> true
   | (h::t) -> false

    is_empty []          (* evaluates to true *)
    is_empty [1]         (* evaluates to false *)
    is_empty [1;2;3]     (* evaluates to false *)
```

More Examples

-
  ```
  let f l =
   match l with (h1::(h2::_)) -> h1 + h2
   – f [1;2;3]
   –   (* evaluates to 3 *)
  ```

-
  ```
  let g l =
   match l with [h1; h2] -> h1 + h2
   – g [1; 2]
   –   (* evaluates to 3 *)
   – g [1; 2; 3]
   –   (* error!  no pattern matches *)
  ```

Two element list [h1;h2]

An Abbreviation

- `let f p = e`, where p is a pattern, is a shorthand for `let f x = match x with p -> e`

- Examples
  ```
  – let hd (h::_) = h
  – let tl (_::t) = t
  – let f (x::y::_) = x + y
  – let g [x; y] = x + y
  ```

- Useful if there’s only one acceptable input

Pattern Matching Lists of Lists

- You can do pattern matching on these as well

- Examples
  - `let addFirsts ((x::_) :: (y::_) :: _) = x + y`
    - `addFirsts [ [1; 2; 3]; [4; 5]; [7; 8; 9] ] = 5`
  - `let addFirstSecond ((x::_)::(_::y::_)::_) = x + y`
    - `addFirstSecond [ [1; 2; 3]; [4; 5]; [7; 8; 9] ] = 6`

- Note: You probably won't do this much or at all
  - You'll mostly write recursive functions over lists
  - We'll see that soon

OCaml Functions Take One Argument

- Recall this example

```
let plus (x, y) = x + y;;
plus (3, 4);;
```

  - It looks like you're passing in two arguments
  - Actually, you're passing in a *tuple* instead
    - And using pattern matching
- Tuples are *constructed* using `(e1, ..., en)`
  - They're like C structs but without field labels, and allocated on the heap
  - Unlike lists, tuples do *not* need to be homogenous
  - E.g., `(1, ["string1"; "string2"])` is a valid tuple
- Tuples are *deconstructed* using pattern matching

Examples with Tuples

- `let plusThree (x, y, z) = x + y + z`
  `let addOne (x, y, z) = (x+1, y+1, z+1)`
  - `plusThree (addOne (3, 4, 5))   (* returns 15 *)`

- `let sum ((a, b), c) = (a+c, b+c)`
  - `sum ((1, 2), 3) = (4, 5)`

- `let plusFirstTwo (x::y::_, a) = (x + a, y + a)`
  - `plusFirstTwo ([1; 2; 3], 4) = (5, 6)`

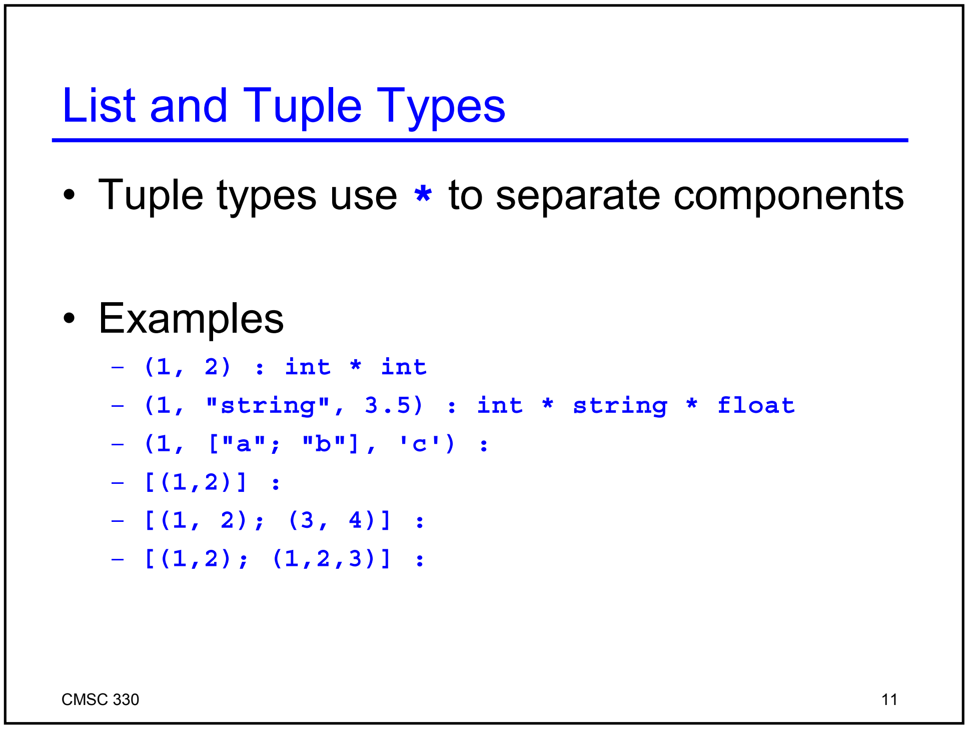
- `let tls (_::xs, _::ys) = (xs, ys)`
  - `tls ([1; 2; 3], [4; 5; 6; 7]) = ([2; 3], [5; 6; 7])`

- Remember, semicolon for lists, comma for tuples
  - `[1, 2] = [(1, 2)] = a list of size one`
  - `(1; 2) = a syntax error`

Another Example

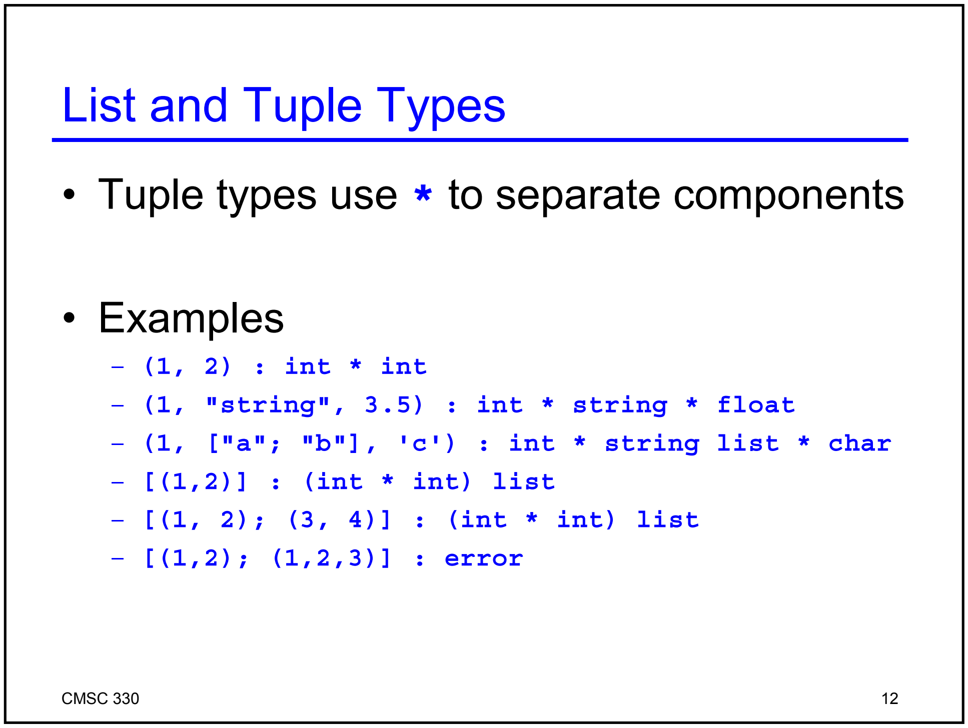
- `let f l = match l with x::(_::y) -> (x,y)`
- What is `f [1;2;3;4]`?

  `(1,[3;4])`



List and Tuple Types

- Tuple types use `*` to separate components
- Examples
  - `(1, 2) : int * int`
  - `(1, "string", 3.5) : int * string * float`
  - `(1, ["a"; "b"], 'c') :`
  - `[(1,2)] :`
  - `[(1, 2); (3, 4)] :`
  - `[(1,2); (1,2,3)] :`



List and Tuple Types

- Tuple types use `*` to separate components
- Examples
  - `(1, 2) : int * int`
  - `(1, "string", 3.5) : int * string * float`
  - `(1, ["a"; "b"], 'c') : int * string list * char`
  - `[(1,2)] : (int * int) list`
  - `[(1, 2); (3, 4)] : (int * int) list`
  - `[(1,2); (1,2,3)] : error`

Type declarations

- type can be used to create new names for types
  - useful for combinations of lists and tuples

- Examples

```
type my_type = int * (int list)
(3, [1; 2]) : my_type

type my_type2 = int * char * (int * float)
(3, ‘a’, (5, 3.0)) : my_type2
```

Polymorphic Types

- Some functions we saw require specific list types
  - `let plusFirstTwo (x::y::_, a) = (x + a, y + a)`
  - `plusFirstTwo : int list * int -> (int * int)`
- But other functions work for any list
  - `let hd (h::_) = h`
  - `hd [1; 2; 3]       (* returns 1 *)`
  - `hd ["a"; "b"; "c"] (* returns "a" *)`
- OCaml gives such functions *polymorphic* types
  - `hd : 'a list -> 'a`
  - this says the function takes a list of any element type `'a`, and returns something of that type

Examples of Polymorphic Types

- `let tl (_::t) = t`
  - `tl : 'a list -> 'a list`
- `let swap (x, y) = (y, x)`
  - `swap : 'a * 'b -> 'b * 'a`
- `let tls (_::xs, _::ys) = (xs, ys)`
  - `tls : 'a list * 'b list  ->  'a list * 'b list`

Tuples Are a Fixed Size

```
# let foo x = match x with
  (a, b) -> a + b
| (a, b, c) -> a + b + c;;
This pattern matches values of type 'a * 'b
  * 'c
but is here used to match values of type 'd
  * 'e
```

- Thus there's never more than one match case with tuples
  - How's this instead?

Conditionals

- Use if...then...else just like C/Java
  - No parentheses and no end

```
if grade >= 90 then
  print_string "You got an A"
else if grade >= 80 then
  print_string "You got a B"
else if grade >= 70 then
  print_string "You got a C"
else
  print_string "You’re not doing so well"
```

Conditionals (cont’d)

- In OCaml, conditionals return a result
  - The value of whichever branch is true/false
  - Like ? : in C, C++, and Java

```
# if 7 > 42 then "hello" else "goodbye";;
- : string = "goodbye"
# let x = if true then 3 else 4;;
x : int = 3
# if false then 3 else 3.0;;
This expression has type float but is here used
  with type int
```

- Putting this together with what we’ve seen earlier, can you write fact, the factorial function?

The Factorial Function

```
let rec fact n =
  if n = 0 then
     1
  else
     n * fact (n-1);;
```

- Notice no return statements
  - So this is pretty much how it needs to be written
- The rec part means “define a recursive function”
  - This is special for technical reasons
  - let x = e1 in e2   x in scope within e2
  - let rec x = e1 in e2   x in scope within e2 *and e1*
    - OCaml will complain if you use let instead of let rec

More examples of let (try to evaluate)

-
  ```
  let x = 1 in x ; x;;
  ```

-
  ```
  let x = x in x;;
  ```

-
  ```
  let x = 4;
  let x = x + 1 in x;;
  ```

-
  ```
  let f n = 10;;
  let f n = if n = 0 then 1 else n * f (n – 1);;
  f 0;;
  f 1;;
  ```

-
  ```
  let f x = f x;;
  ```

More examples of let

-
  ```
  let x = 1 in x ; x;;  (* error, x is unbound *)
  ```

-
  ```
  let x = x in x;;  (* error, x is unbound *)
  ```

-
  ```
  let x = 4;
  let x = x + 1 in x;;  (* 5 *)
  ```

-
  ```
  let f n = if n = 0 then 1 else n * f (n - 1);;
  f 0;; (* 1 *)
  f 1;; (* 1 *)
  ```

-
  ```
  let f x = f x;;  (* error *)
  ```

Recursion = Looping

- Recursion is essentially the only way to iterate
  - (The only way we’re going to talk about)
- Another example

```
let rec print_up_to (n, m) =
  print_int n; print_string "\n";
  if n < m then print_up_to (n + 1, m)
```

Lists and Recursion

- Lists have a recursive structure
  - And so most functions over lists will be recursive

```
let rec length l = match l with
     [] -> 0
   | (_::t) -> 1 + (length t)
```

  - This is just like an inductive definition
    - *The length of the empty list is zero*
    - *The length of a nonempty list is 1 plus the length of the tail*
  - Type of length function?