CMSC 330: Organization of Programming Languages

Functional Programming with OCaml

Background

- 1973 – ML developed at Univ. of Edinburgh
  - Part of a theorem proving system LCF
    - The Logic of Computable Functions
- SML/NJ ("Standard ML of New Jersey")
  - http://www.smlnj.org
  - Developed at Bell Labs and Princeton; now Yale, AT&T Research, Univ. of Chicago (among others)
- OCaml
  - http://www.ocaml.org
  - Developed at INRIA (The French National Institute for Research in Computer Science)

Dialects of ML

- Other dialects include MoscowML, ML Kit, Concurrent ML, etc.
  - But SML/NJ and OCaml are most popular
  - O = "Objective," but probably won't cover objects
- Languages all have the same core ideas
  - But small and annoying syntactic differences
  - So you should not buy a book with ML in the title
    - Because it probably won't cover OCaml

Features of ML

- Higher-order functions
  - Functions can be parameters and return values
- "Mostly functional"
- Data types and pattern matching
  - Convenient for certain kinds of data structures
- Type inference
  - No need to write types in the source language, but the language is statically typed
  - Supports *parametric polymorphism* (*generics* in Java, *templates* in C++)
- Exceptions
- Garbage collection

Functional languages

- In a pure functional language, every program is just an expression evaluation

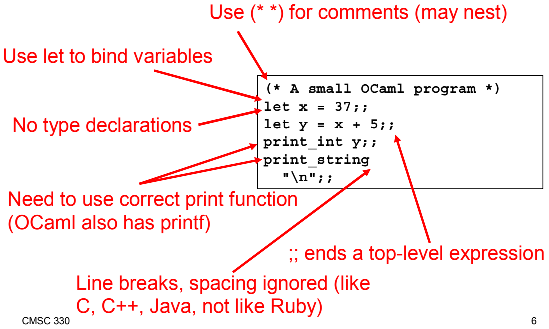
let add1 x = x + 1;;

let rec add (x,y) = if x=0 then y else add(x-1, add1(y));;

add(2,3) = add(1,add1(3)) = add(0,add1(add1(3)))
= add1(add1(3)) = add1(3+1) = 3+1+1
= 5

OCaml has this basic behavior, but has additional features to ease the programming process.
- Less emphasis on data storage
- More emphasis on function execution

A Small OCaml Program- Things to Notice



Use (* *) for comments (may nest)

Use let to bind variables

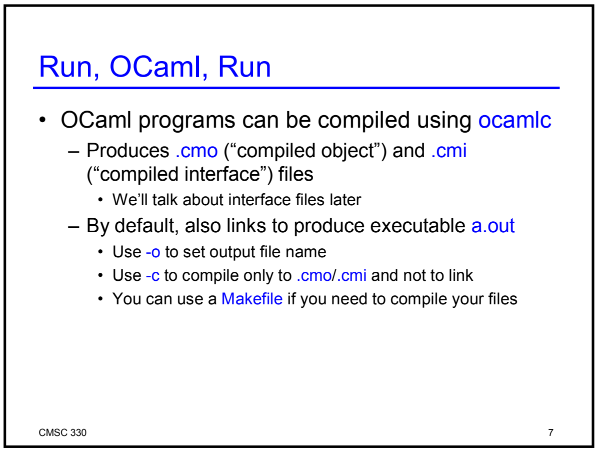
No type declarations

```
(* A small OCaml program *)
let x = 37;;
let y = x + 5;;
print_int y;;
print_string
  "\n";;
```

Need to use correct print function
(OCaml also has printf)

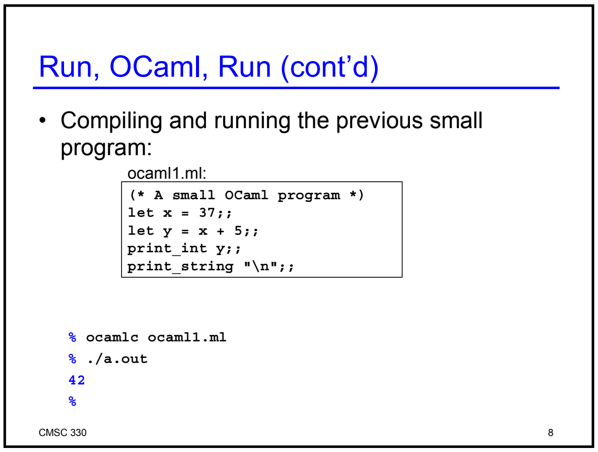
;; ends a top-level expression

Line breaks, spacing ignored (like
C, C++, Java, not like Ruby)



Run, OCaml, Run

- OCaml programs can be compiled using ocamlc
  - Produces .cmo (“compiled object”) and .cmi (“compiled interface”) files
    - We’ll talk about interface files later
  - By default, also links to produce executable a.out
    - Use -o to set output file name
    - Use -c to compile only to .cmo/.cmi and not to link
    - You can use a Makefile if you need to compile your files



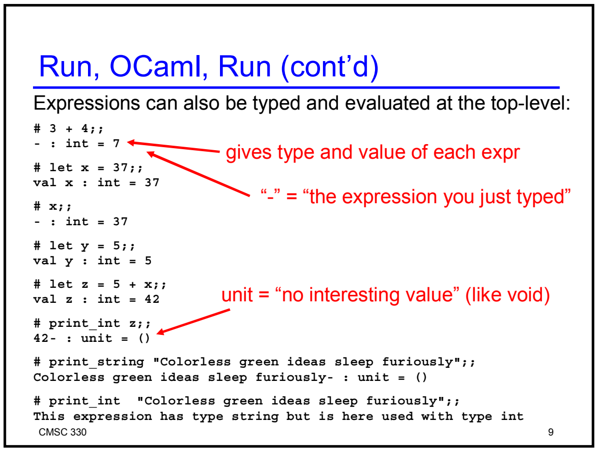
Run, OCaml, Run (cont’d)

- Compiling and running the previous small program:

ocaml1.ml:

```
(* A small OCaml program *)
let x = 37;;
let y = x + 5;;
print_int y;;
print_string "\n";;
```

```
% ocamlc ocaml1.ml
% ./a.out
42
%
```



Run, OCaml, Run (cont’d)

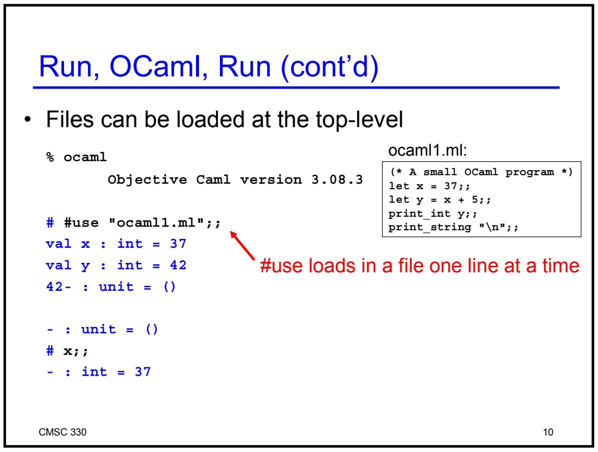
Expressions can also be typed and evaluated at the top-level:

```
# 3 + 4;;
- : int = 7

# let x = 37;;
val x : int = 37

# x;;
- : int = 37

# let y = 5;;
val y : int = 5

# let z = 5 + x;;
val z : int = 42

# print_int z;;
42- : unit = ()

# print_string "Colorless green ideas sleep furiously";;
Colorless green ideas sleep furiously- : unit = ()

# print_int  "Colorless green ideas sleep furiously";;
This expression has type string but is here used with type int
```

gives type and value of each expr

“-” = “the expression you just typed”

unit = “no interesting value” (like void)



Run, OCaml, Run (cont’d)

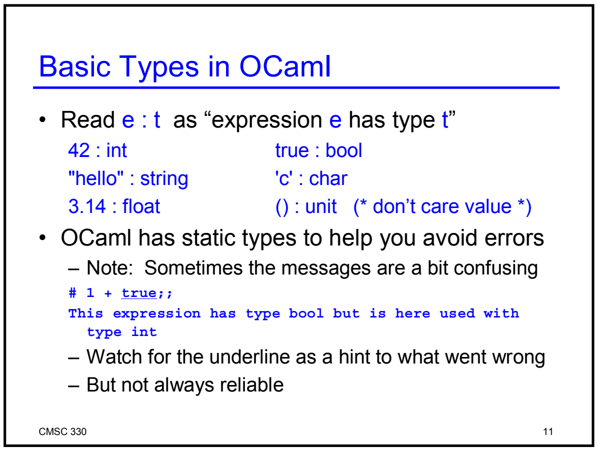
- Files can be loaded at the top-level

```
% ocaml
        Objective Caml version 3.08.3

# #use "ocaml1.ml";;
val x : int = 37
val y : int = 42
42- : unit = ()

- : unit = ()
# x;;
- : int = 37
```

ocaml1.ml:

```
(* A small OCaml program *)
let x = 37;;
let y = x + 5;;
print_int y;;
print_string "\n";;
```

#use loads in a file one line at a time



Basic Types in OCaml

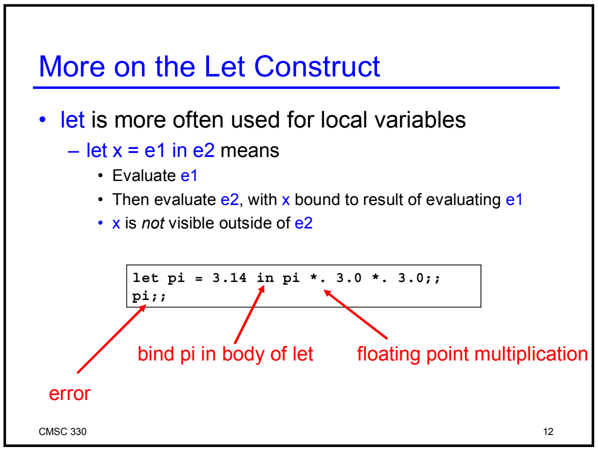
- Read e : t as “expression e has type t”

42 : int	true : bool
"hello" : string	'c' : char
3.14 : float	() : unit (* don’t care value *)

- OCaml has static types to help you avoid errors
  - Note: Sometimes the messages are a bit confusing

```
# 1 + true;;
This expression has type bool but is here used with
  type int
```

  - Watch for the underline as a hint to what went wrong
  - But not always reliable



More on the Let Construct

- let is more often used for local variables
  - let x = e1 in e2 means
    - Evaluate e1
    - Then evaluate e2, with x bound to result of evaluating e1
    - x is *not* visible outside of e2

```
let pi = 3.14 in pi *. 3.0 *. 3.0;;
pi;;
```

bind pi in body of let

floating point multiplication

error

More on the Let Construct (cont'd)

- Compare to similar usage in Java/C

```
let pi = 3.14 in
  pi *. 3.0 *. 3.0;;
pi;;
```

```
{
  float pi = 3.14;

  pi * 3.0 * 3.0;
}
pi;
```

- In the top-level, omitting in means "from now on":
  # let pi = 3.14;;
  (* pi is now bound in the rest of the top-level scope *)

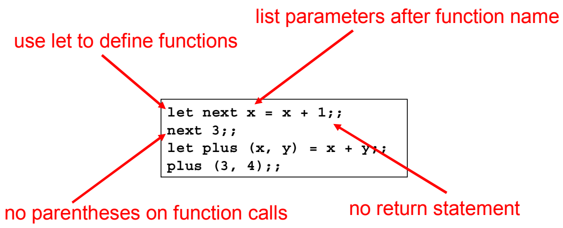
Nested Let

- Uses of let can be nested

```
let pi = 3.14 in
let r = 3.0 in
  pi *. r *. r;;
(* pi, r no longer in scope *)
```

```
{
  float pi = 3.14;
  float r = 3.0;

  pi * r * r;
}
/* pi, r not in scope */
```

Defining Functions


list parameters after function name
use let to define functions
no parentheses on function calls
no return statement

```
let next x = x + 1;;
next 3;;
let plus (x, y) = x + y;;
plus (3, 4);;
```

Local Variables

- You can use let inside of functions for locals

```
let area r =
  let pi = 3.14 in
  pi *. r *. r
```

  – And you can use as many lets as you want

```
let area d =
  let pi = 3.14 in
  let r = d /. 2.0 in
  pi *. r *. r
```

Function Types

- In OCaml, `->` is the function type constructor
  – The type `t1 -> t2` is a function with argument or *domain* type `t1` and return or *range* type `t2`
- Examples

```
– let next x = x + 1 (* type int -> int *)
– let fn x = (float_of_int x) *. 3.14
                     (* type int -> float *)
– print_string       (* type string -> unit *)
```

- Type a function name at top level to get its type

Type Annotations

- The syntax `(e : t)` asserts that "`e` has type `t`"
  – This can be added anywhere you like

```
let (x : int) = 3
let z = (x : int) + 5
```

- Use to give functions parameter and return types

```
let fn (x:int):float =
       (float_of_int x) *. 3.14
```

  – Note special position for return type
  – Thus `let g x:int =` ... means `g` returns `int`
- Very useful for debugging, especially for more complicated types

;; versus ;

- ;; ends an expression in the top-level of OCaml
  - Use it to say: "Give me the value of this expression"
  - Not used in the body of a function
  - Not needed after each function definition
    - Though for now it won't hurt if used there
- e1; e2 evaluates e1 and then e2, and returns e2

```
let print_both (s, t) = print_string s; print_string t;
                        "Printed s and t."
```

  - notice no ; at end---it's a *separator*, not a *terminator*

```
print_both (”Colorless green ", ”ideas sleep")
```

Prints `"Colorless green ideas sleep"`, and returns `"Printed s and t."`

Lists in OCaml

- The basic data structure in OCaml is the list
  - Lists are written as [e1; e2; ...; en]

```
# [1;2;3]
- : int list = [1;2;3]
```

  - Notice int list – lists must be *homogeneous*
  - The empty list is []

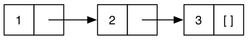
```
# []
- : 'a list
```

  - The 'a means "a list containing anything"
    - we'll see more about this later
  - Warning: Don't use a comma instead of a semicolon
    - Means something different (we'll see in a bit)

Consider a Linked List in C

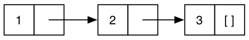
```
struct list {
  int elt;
  struct list *next;
};
…
struct list *l;
…
i = 0;
while (l != NULL) {
  i++;
  l = l->next;
}
```

Lists in OCaml are Linked



- [1;2;3] is represented above
  - A nonempty list is a pair (element, rest of list)
  - The element is the *head* of the list
  - The pointer is the *tail* or *rest* of the list
    - ...which is itself a list!
- Thus in math a list is either
  - The empty list []
  - Or a pair consisting of an element and a list
    - This recursive structure will come in handy shortly

Lists are Linked (cont'd)



- :: prepends an element to a list
  - h::t is the list with h as the element at the beginning and t as the "rest"
  - :: is called a *constructor*, because it builds a list
  - Although it's not emphasized, :: does allocate memory
- Examples

```
3::[]              (* The list [3] *)
2::(3::[])         (* The list [2; 3] *)
1::(2::(3::[]))    (* The list [1; 2; 3] *)
```

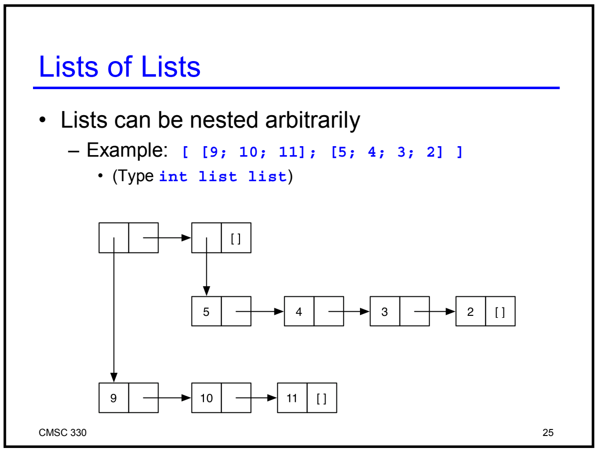
More Examples

```
# let y = [1;2;3] ;;
val y : int list = [1; 2; 3]
# let x = 4::y ;;
val x : int list = [4; 1; 2; 3]
# let z = 5::y ;;
val z : int list = [5; 1; 2; 3]
```

- *not* modifying existing lists, just creating new lists

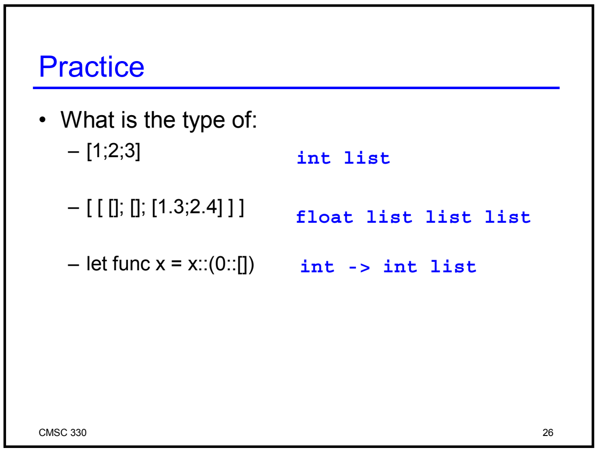
```
# let w = [1;2]::y ;;
This expression has type int list but is here
  used with type int list list
```

- The left argument of :: is an element
- Can you construct a list y such that [1;2]::y makes sense?



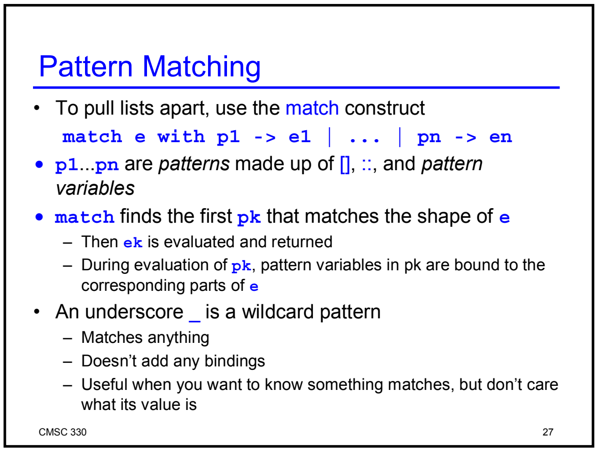
Lists of Lists

- Lists can be nested arbitrarily
  - Example: `[ [9; 10; 11]; [5; 4; 3; 2] ]`
    - (Type `int list list`)



Practice

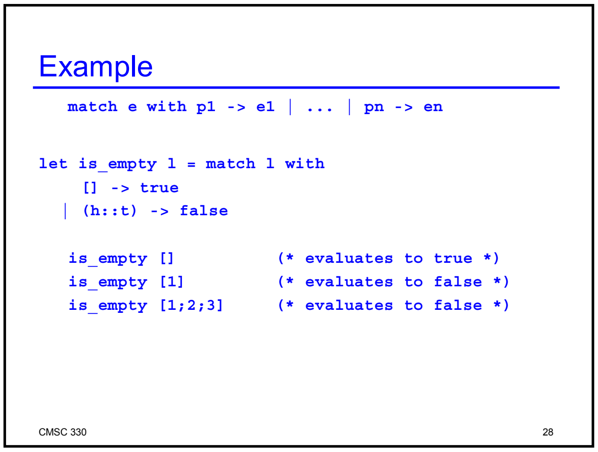
- What is the type of:
  - [1;2;3] `int list`
  - [[[]; []; [1.3;2.4]]] `float list list list`
  - let func x = x::(0::[]) `int -> int list`



Pattern Matching

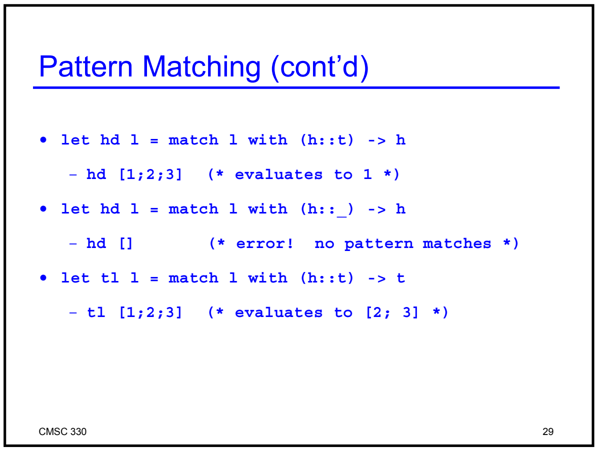
- To pull lists apart, use the match construct

  `match e with p1 -> e1 | ... | pn -> en`
- `p1`...`pn` are *patterns* made up of [], ::, and *pattern variables*
- `match` finds the first `pk` that matches the shape of `e`
  - Then `ek` is evaluated and returned
  - During evaluation of `pk`, pattern variables in pk are bound to the corresponding parts of `e`
- An underscore _ is a wildcard pattern
  - Matches anything
  - Doesn't add any bindings
  - Useful when you want to know something matches, but don't care what its value is



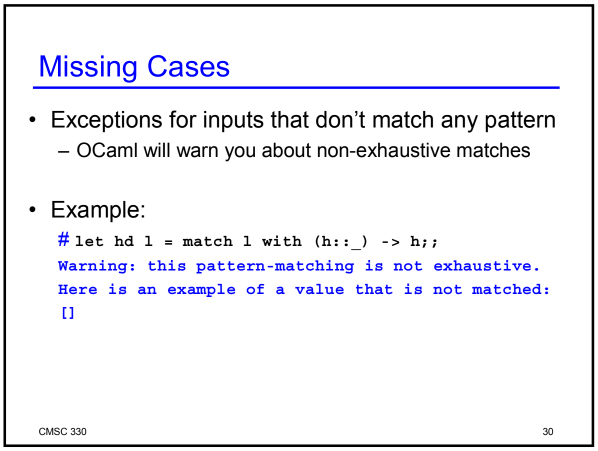
Example

```
   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 *)
```



Pattern Matching (cont'd)

- `let hd l = match l with (h::t) -> h`
  - `hd [1;2;3]   (* evaluates to 1 *)`
- `let hd l = match l with (h::_) -> h`
  - `hd []        (* error!  no pattern matches *)`
- `let tl l = match l with (h::t) -> t`
  - `tl [1;2;3]   (* evaluates to [2; 3] *)`



Missing Cases

- Exceptions for inputs that don't match any pattern
  - OCaml will warn you about non-exhaustive matches
- Example:

```
# let hd l = match l with (h::_) -> h;;
Warning: this pattern-matching is not exhaustive.
Here is an example of a value that is not matched:
[]
```