CMSC 330: Organization of Programming Languages

OCaml 1
Functional Programming

Dialects of ML

- ML (Meta Language)
  - Univ. of Edinburgh,1973
  - Part of a theorem proving system LCF
    - The Logic of Computable Functions
- SML/NJ (Standard ML of New Jersey)
  - Bell Labs and Princeton, 1990
  - Now Yale, AT&T Research, Univ. of Chicago, etc…
- OCaml (Objective CAML)
  - INRIA, 1996
  - French Nat'l Institute for Research in Computer Science

Dialects of ML (cont.)

- Other dialects
  - MoscowML, ML Kit, Concurrent ML, etc…
  - SML/NJ and OCaml are most popular
- 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

- "Mostly functional"
  - Some assignments
- Higher-order functions
  - Functions can be parameters and return values
- 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++

Features of ML (cont.)

- Data types and pattern matching
  - Convenient for certain kinds of data structures
- 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
```

Functional Languages (cont.)

- OCaml has similar basic behavior
  - Program = expression evaluation
- But has additional features
  - To ease the programming process
  - Features support
    - Less emphasis on data storage
    - More emphasis on function execution

A Small OCaml Program – Things to Notice

Use let to bind variables

Use (* *) for comments (may nest)

No type declarations

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

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

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

;; ends a top-level expression

OCaml Interpreter

Expressions can 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)

OCaml Interpreter (cont.)

- Files can be loaded at 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

```
(* 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

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
- Not needed for this course

Run, OCaml, Run (cont.)

- Compiling & running the previous small program

ocaml1.ml

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

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

This Lecture

- Basic OCaml types
- Defining variables & functions with let
- Lists
- Pattern matching with match

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

The Let Construct

- let is often used for defining 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;;
```

error

bind pi in body of let

floating point multiplication

The Let Construct (cont.)

- 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 *)

;; 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 p (s,t) = print_int s; print_int t; "Done!"
```

  - Notice no ; at end
  - ; is a separator, not a terminator
  - Invoking `p (1,2)`
    - Prints `"1 2"`
    - Returns `"Done!"`

Examples – Semicolon

- Definition
  - e1 ; e2 (* evaluate e1, evaluate e2, return e2)
- 1 ; 2 ;;
  - (* 2 – value of 2nd expression is returned *)
- (1 + 2) ; 4 ;;
  - (* 4 – value of 2nd expression is returned *)
- 1 + (2 ; 4) ;;
  - (* 5 – value of 2nd expression is returned to 1 + *)
- 1 + 2 ; 4 ;;
  - (* 4 – because + has higher precedence than ; *)

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

Use let to define functions

List parameters after function name

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

No parentheses on function calls

No return statement

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

Lists in OCaml

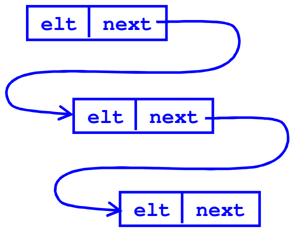
- The basic data structure in OCaml is the list
  - Lists are written as [e1; e2; ...; en]
    `# [1;2;3]`
    `- : int list = [1;2;3]`
  - Notice type of list is `int list`
    - Lists must be homogeneous

Lists in OCaml (cont.)

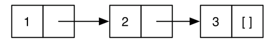
- More on OCaml lists
  - The empty list is [ ]
    `# [ ]`
    `- : 'a list`
  - The `'a` means "a list containing anything"
    - We'll find out more about this later
  - List elements are separated using semicolons
  - Warning: Don't use a comma instead of a semicolon
    - Means something different (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;
}
```

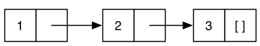


Lists in OCaml are Linked



- [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.)



- :: 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 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]
```

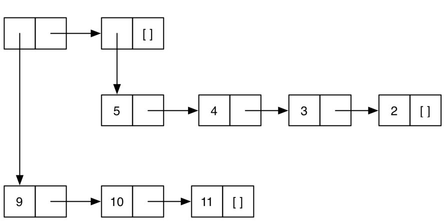
- not modifying existing lists, just creating new lists

```
# 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 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`

Pattern Matching Example

- Match syntax
  - `match e with p1 -> e1 | ... | pn -> en`
- Code 1
  - ```
    let is_empty l = match l with
          [] -> true
          | (h::t) -> false
    ```
- Outputs
  - `is_empty []    (* evaluates to true  *)`
  - `is_empty [1]   (* evaluates to false *)`
  - `is_empty [1;2] (* evaluates to false *)`

Pattern Matching Example (cont.)

- Code 2
  - `let hd l = match l with (h::t) -> h`
- Outputs
  - `hd [1;2;3] (* evaluates to 1 *)`
  - `hd [1;2]   (* evaluates to 1 *)`
  - `hd [1]     (* evaluates to 1 *)`
  - `hd []      (* Exception: Match failure *)`

Pattern Matching Example (cont.)

- Code 3
  - `let tl l = match l with (h::t) -> t`
- Outputs
  - `tl [1;2;3] (* evaluates to [2;3] *)`
  - `tl [1;2]   (* evaluates to [2] *)`
  - `tl [1]     (* evaluates to [ ] *)`
  - `tl []      (* Exception: Match failure *)`

Pattern Matching – Wildcards

- 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
- In previous examples
  - Many values of `h` or `t` ignored
  - Can replace with wildcard _
  - Code behavior is identical

Pattern Matching – Wildcards (cont.)

- Code using _
  - ```
    let is_empty l = match l with
          [] -> true | (_::_) -> false
    ```
  - `let hd l = match l with (h::_) -> h`
  - `let tl l = match l with (_::t) -> t`
- Outputs
  - `is_empty[1] (* evaluates to false *)`
  - `is_empty[ ] (* evaluates to true  *)`
  - `hd [1;2;3]  (* evaluates to 1     *)`
  - `tl [1;2;3]  (* evaluates to [2;3] *)`
  - `hd [1]      (* evaluates to 1     *)`
  - `tl [1]      (* evaluates to [ ]   *)`

Pattern Matching – Missing Cases

- When pattern is defined
  - OCaml will warn you about non-exhaustive matches
- When pattern is used
  - Exceptions for inputs that don't match any pattern
- 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:
[]
# hd [];;
Exception: Match_failure ("", 1, 11).
```


Pattern Matching – An Abbreviation

- `let f p = e`, where p is a pattern
  - is 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

- Can pattern match on lists of lists as well
- Examples
  - `let addFirsts`
    `((x::_) :: (y::_) :: _) = x + y`
    `addFirsts [[1;2];[4;5];[7;8;9]] = 5`
  - `let addFirstSecond`
    `(x::_)::(_::y::_)::_) = x + y`
    `addFirstSecond [[1;2];[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 instead