A Second Look At ML

Outline

- Patterns
- Local variable definitions
- A sorting example

Two Patterns You Already Know

- We have seen that ML functions take a single parameter:

```
fun f n = n*n;
```

- We have also seen how to specify functions with more than one input by using tuples:

```
fun f (a, b) = a*b;
```

- Both **`n`** and **`(a, b)`** are *patterns*. The **`n`** matches and binds to any argument, while **`(a,b)`** matches any 2-tuple and binds **`a`** and **`b`** to its components

Underscore As A Pattern

```
- fun f _ = "yes";
val f = fn : 'a -> string
- f 34.5;
val it = "yes" : string
- f [];
val it = "yes" : string
```

- The underscore can be used as a pattern
- It matches anything, but does not bind it to a variable
- Preferred to:

```
fun f x = "yes";
```

Constants As Patterns

```
- fun f 0 = "yes";
Warning: match nonexhaustive
          0 => ...
val f = fn : int -> string
- f 0;
val it = "yes" : string
```

- Any constant of an equality type can be used as a pattern
- But not:

```
fun f 0.0 = "yes";
```

Non-Exhaustive Match

- In that last example, the type of **`f`** was **`int -> string`**, but with a “match non-exhaustive” warning
- Meaning: **`f`** was defined using a pattern that didn’t cover all the domain type (**`int`**)
- So you may get runtime errors like this:

```
- f 0;
val it = "yes" : string
- f 1;
uncaught exception nonexhaustive match failure
```

Lists Of Patterns As Patterns

```
- fun f [a,_] = a;
Warning: match nonexhaustive
          a :: _ :: nil => ...
val f = fn : 'a list -> 'a
- f [#"f",#"g"];
val it = #"f" : char
```

- You can use a list of patterns as a pattern
- This example matches any list of length 2
- It treats **`a`** and **`_`** as sub-patterns, binding **`a`** to the first list element

Cons Of Patterns As A Pattern

```
- fun f (x::xs) = x;
Warning: match nonexhaustive
          x :: xs => ...
val f = fn : 'a list -> 'a
- f [1,2,3];
val it = 1 : int
```

- You can use a cons of patterns as a pattern
- **`x::xs`** matches any non-empty list, and binds **`x`** to the head and **`xs`** to the tail
- Parens around **`x::xs`** are for precedence

ML Patterns So Far

- A variable is a pattern that matches anything, and binds to it
- A `_` is a pattern that matches anything
- A constant (of an equality type) is a pattern that matches only that constant
- A tuple of patterns is a pattern that matches any tuple of the right size, whose contents match the sub-patterns
- A list of patterns is a pattern that matches any list of the right size, whose contents match the sub-patterns
- A cons (`::`) of patterns is a pattern that matches any non-empty list whose head and tail match the sub-patterns

Multiple Patterns for Functions

```
- fun f 0 = "zero"
= |   f 1 = "one";
Warning: match nonexhaustive
          0 => ...
          1 => ...
val f = fn : int -> string;
- f 1;
val it = "one" : string
```

- You can define a function by listing alternate patterns

Syntax

<*fun-def*> `::=` **`fun`** <*fun-bodies*> **`;`**
<*fun-bodies*> `::=` <*fun-body*>
| <*fun-body*> **`'|'`** <*fun-bodies*>
<*fun-body*> `::=` <*fun-name*> <*pattern*> **`=`** <*expression*>

- To list alternate patterns for a function
- You must repeat the function name in each alternative

Overlapping Patterns

```
- fun f 0 = "zero"
= |   f _ = "non-zero";
val f = fn : int -> string;
- f 0;
val it = "zero" : string
- f 34;
val it = "non-zero" : string
```

- Patterns may overlap
- ML uses the first match for a given argument

Pattern-Matching Style

- These definitions are equivalent:

```
fun f 0 = "zero"
|   f _ = "non-zero";
fun f n =
  if n = 0 then "zero"
  else "non-zero";
```

- But the pattern-matching style usually preferred in ML
- It often gives shorter and more legible functions

Pattern-Matching Example

Original (from Chapter 5):

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

Rewritten using patterns:

```
fun fact 0 = 1
|   fact n = n * fact(n-1);
```

Pattern-Matching Example

Original (from Chapter 5):

```
fun reverse L =
   if null L then nil
   else reverse(tl L) @ [hd L];
```

Improved using patterns:

```
fun reverse nil = nil
|   reverse (first::rest) =
      reverse rest @ [first];
```

More Examples

This structure occurs frequently in recursive functions that operate on lists: one alternative for the base case (**`nil`**) and one alternative for the recursive case (**`first::rest`**).

Adding up all the elements of a list:

```
fun f nil = 0
|   f (first::rest) = first + f rest;
```

Counting the true values in a list:

```
fun f nil = 0
|   f (true::rest) = 1 + f rest
|   f (false::rest) = f rest;
```

More Examples

Making a new list of integers in which each is one greater than in the original list:

```
fun f nil = nil
|   f (first::rest) = first+1 :: f rest;
```

A Restriction

- You can't use the same variable more than once in the same pattern
- This is not legal:

```
fun f (a,a) = … for pairs of equal elements
|   f (a,b) = … for pairs of unequal elements
```

- You must use this instead:

```
fun f (a,b) =
  if (a=b) then … for pairs of equal elements
  else … for pairs of unequal elements
```

The **`polyEqual`** Warning

```
- fun eq (a,b) = if a=b then 1 else 0;
Warning: calling polyEqual
val eq = fn : ''a * ''a -> int
- eq (1,3);
val it = 0 : int
- eq ("abc","abc");
val it = 1 : int
```

- Warning for an equality comparison, when the runtime type cannot be resolved
- OK to ignore: this kind of equality test is inefficient, but can’t always be avoided

Patterns Everywhere

```
- val (a,b) = (1,2.3);
val a = 1 : int
val b = 2.3 : real
- val a::b = [1,2,3,4,5];
Warning: binding not exhaustive
          a :: b = ...
val a = 1 : int
val b = [2,3,4,5] : int list
```

- Patterns are not just for function definition
- Here we see that you can use them in a **`val`**
- More ways to use patterns, later

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Local Variable Definitions

- When you use **`val`** at the top level to define a variable, it is visible from that point forward
- There is a way to restrict the scope of definitions: the **`let`** expression

<let-exp> `::=` **`let`** *<definitions>* **`in`** *<expression>* **`end`**

Example with **`let`**

```
- let val x = 1 val y = 2 in x+y end;
val it = 3 : int;
- x;
Error: unbound variable or constructor: x
```

- The value of a **`let`** expression is the value of the expression in the **`in`** part
- Variables defined with **`val`** between the **`let`** and the **`in`** are visible only from the point of declaration up to the **`end`**

Proper Indentation for `let`

```
let
  val x = 1
  val y = 2
in
  x+y
end
```

- For readability, use multiple lines and indent `let` expressions like this
- Some ML programmers put a semicolon after each `val` declaration in a `let`

Long Expressions with `let`

```
fun days2ms days =
  let
    val hours = days * 24.0
    val minutes = hours * 60.0
    val seconds = minutes * 60.0
  in
    seconds * 1000.0
  end;
```

- The **`let`** expression allows you to break up long expressions and name the pieces
- This can make code more readable

Patterns with `let`

```
fun halve nil = (nil, nil)
|   halve [a] = ([a], nil)
|   halve (a::b::cs) =
      let
        val (x, y) = halve cs
      in
        (a::x, b::y)
      end;
```

- By using patterns in the declarations of a **`let`**, you can get easy "deconstruction"
- This example takes a list argument and returns a pair of lists, with half in each

Again, Without Good Patterns

```
let
  val halved = halve cs
  val x = #1 halved
  val y = #2 halved
in
  (a::x, b::y)
end;
```

- In general, if you find yourself using **#** to extract an element from a tuple, think twice
- Pattern matching usually gives a better solution

halve At Work

```
- fun halve nil = (nil, nil)
= |   halve [a] = ([a], nil)
= |   halve (a::b::cs) =
=       let
=         val (x, y) = halve cs
=       in
=         (a::x, b::y)
=       end;
val halve = fn : 'a list -> 'a list * 'a list
- halve [1];
val it = ([1],[]) : int list * int list
- halve [1,2];
val it = ([1],[2]) : int list * int list
- halve [1,2,3,4,5,6];
val it = ([1,3,5],[2,4,6]) : int list * int list
```

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Merge Sort

- The **`halve`** function divides a list into two nearly-equal parts
- This is the first step in a merge sort
- For practice, we will look at the rest

Example: Merge

```
fun merge (nil, ys) = ys
|   merge (xs, nil) = xs
|   merge (x::xs, y::ys) =
      if (x < y) then x :: merge(xs, y::ys)
      else y :: merge(x::xs, ys);
```

- Merges two sorted lists
- Note: default type for **`<`** is **`int`**

Merge At Work

```
- fun merge (nil, ys) = ys
= |   merge (xs, nil) = xs
= |   merge (x::xs, y::ys) =
=        if (x < y) then x :: merge(xs, y::ys)
=        else y :: merge(x::xs, ys);
val merge = fn : int list * int list -> int list
- merge ([2],[1,3]);
val it = [1,2,3] : int list
- merge ([1,3,4,7,8],[2,3,5,6,10]);
val it = [1,2,3,3,4,5,6,7,8,10] : int list
```

Example: Merge Sort

```
fun mergeSort nil = nil
|   mergeSort [a] = [a]
|   mergeSort theList =
      let
        val (x, y) = halve theList
      in
        merge(mergeSort x, mergeSort y)
      end;
```

- Merge sort of a list
- Type is **`int list -> int list`**, because of type already found for **`merge`**

Merge Sort At Work

```
- fun mergeSort nil = nil
= |   mergeSort [a] = [a]
= |   mergeSort theList =
=       let
=         val (x, y) = halve theList
=       in
=         merge(mergeSort x, mergeSort y)
=       end;
val mergeSort = fn : int list -> int list
- mergeSort [4,3,2,1];
val it = [1,2,3,4] : int list
- mergeSort [4,2,3,1,5,3,6];
val it = [1,2,3,3,4,5,6] : int list
```

Nested Function Definitions

- You can define local functions, just like local variables, using a **`let`**
- You should do it for helper functions that you don't think will be useful by themselves
- We can hide **`halve`** and **`merge`** from the rest of the program this way
- Another potential advantage: inner function can refer to variables from outer one (as we will see in Chapter 12)

```
(* Sort a list of integers. *)
fun mergeSort nil = nil
|   mergeSort [e] = [e]
|   mergeSort theList =
      let
        (* From the given list make a pair of lists
         * (x,y), where half the elements of the
         * original are in x and half are in y. *)
        fun halve nil = (nil, nil)
        |   halve [a] = ([a], nil)
        |   halve (a::b::cs) =
              let
                val (x, y) = halve cs
              in
                (a::x, b::y)
              end;
```

continued…

```
  (* Merge two sorted lists of integers into
   * a single sorted list. *)
  fun merge (nil, ys) = ys
  |   merge (xs, nil) = xs
  |   merge (x::xs, y::ys) =
        if (x < y) then x :: merge(xs, y::ys)
        else y :: merge(x::xs, ys);

  val (x, y) = halve theList
in
  merge(mergeSort x, mergeSort y)
end;
```

Commenting

- Everything between `(*` and `*)` in ML is a comment
- You should (at least) comment every function definition, as in any language
  - what parameters does it expect
  - what function does it compute
  - how does it do it (if non-obvious)
  - etc.