CSE341: Programming Languages

Lecture 5
More Datatypes and Pattern-Matching

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Useful examples

Let’s fix the fact that our only example datatype so far was silly…

• Enumerations, including carrying other data

```plaintext
datatype suit = Club | Diamond | Heart | Spade
datatype card_value = Jack | Queen | King
                     | Ace | Num of int
```

• Alternate ways of identifying real-world things/people

```plaintext
datatype id = StudentNum of int
            | Name of string
            * (string option)
            * string
```
**Don’t do this**

Unfortunately, bad training and languages that make one-of types inconvenient lead to common *bad style* where each-of types are used where one-of types are the right tool.

```latex
(* use the studen_num and ignore other fields unless the student_num is ~1 *)
{ student_num : int,
  first       : string,
  middle      : string option,
  last        : string }
```

- Approach gives up all the benefits of the language enforcing every value is one variant, you don’t forget branches, etc.

- And makes it less clear what you are doing
That said…

But if instead the point is that every “person” in your program has a name and maybe a student number, then each-of is the way to go:

```plaintext
{ student_num : int option,
  first       : string,
  middle      : string option,
  last        : string }
```
Expression Trees

A more exciting (?) example of a datatype, using self-reference

```ml
datatype exp = Constant of int
| Negate of exp
| Add of exp * exp
| Multiply of exp * exp
```

An expression in ML of type `exp`:

```
Add (Constant (10+9), Negate (Constant 4))
```

How to picture the resulting value in your head:

```
Add
   /
  /   /
Constant Negate
   /     /
19   Constant
    /     /
   4
```
Recursion

Not surprising:
Functions over recursive datatypes are usually recursive

```
fun eval e =
  case e of
    Constant i => i
    | Negate e2 => ~ (eval e2)
    | Add(e1,e2) => (eval e1) + (eval e2)
    | Multiply(e1,e2) => (eval e1) * (eval e2)
```
Putting it together

```ml
datatype exp = Constant of int
  | Negate of exp
  | Add of exp * exp
  | Multiply of exp * exp
```

Let's define `max_constant : exp -> int`

Good example of combining several topics as we program:
- Case expressions
- Local helper functions
- Avoiding repeated recursion
- Simpler solution by using library functions

See the `.sml` file…
Careful definitions

When a language construct is “new and strange,” there is more reason to define the evaluation rules precisely…

… so let’s review datatype bindings and case expressions “so far”
  – Extensions to come but won’t invalidate the “so far”
**Datatype bindings**

\[
\text{datatype } t = C_1 \text{ of } t_1 \mid C_2 \text{ of } t_2 \mid \ldots \mid C_n \text{ of } t_n
\]

Adds type \( t \) and constructors \( C_i \) of type \( t_i \rightarrow t \)
- \( C_i \ v \) is a value, i.e., the result “includes the tag”

Omit “of \( t \)” for constructors that are just tags, no underlying data
- Such a \( C_i \) is a value of type \( t \)

Given an expression of type \( t \), use case expressions to:
- See which variant (tag) it has
- Extract underlying data once you know which variant
Datatype bindings

\[
\text{case } e \text{ of } p_1 \Rightarrow e_1 \mid p_2 \Rightarrow e_2 \mid \ldots \mid p_n \Rightarrow e_n
\]

• As usual, can use a case expressions anywhere an expression goes
  – Does not need to be whole function body, but often is

• Evaluate \( e \) to a value, call it \( v \)

• If \( p_i \) is the first pattern to match \( v \), then result is evaluation of \( e_i \) in environment “extended by the match”

• Pattern \( C_i(x_1,\ldots,x_n) \) matches value \( C_i(v_1,\ldots,v_n) \) and extends the environment with \( x_1 \) to \( v_1 \) \ldots \( x_n \) to \( v_n \)
  – For “no data” constructors, pattern \( C_i \) matches value \( C_i \)
Recursive datatypes

Datatype bindings can describe recursive structures
- Have seen arithmetic expressions
- Now, linked lists:

```plaintext
datatype my_int_list = Empty
  | Cons of int * my_int_list

val x = Cons(4,Cons(23,Cons(2008,Empty)))

fun append_my_list (xs,ys) =
  case xs of
    Empty => ys
  | Cons(x,xs') => Cons(x, append_my_list(xs',ys))
```

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Options are datatypes

Options are just a predefined datatype binding
  – **NONE** and **SOME** are *constructors*, not just functions
  – So use pattern-matching not **isSome** and **valOf**

```haskell
fun inc_or_zero intoption =
  case intoption of
    NONE => 0
  | SOME i => i+1
```
Lists are datatypes

Do not use `hd`, `tl`, or `null` either
- `[]` and `::` are constructors too
- (strange syntax, particularly `infix`)

```plaintext
fun sum_list xs =
    case xs of
        [] => 0
        | x::xs' => x + sum_list xs'

fun append (xs,ys) =
    case xs of
        [] => ys
        | x::xs' => x :: append (xs',ys)
```
Why pattern-matching

• Pattern-matching is better for options and lists for the same reasons as for all datatypes
  – No missing cases, no exceptions for wrong variant, etc.

• We just learned the other way first for pedagogy
  – Do not use isSome, valOf, null, hd, tl on Homework 2

• So why are null, tl, etc. predefined?
  – For passing as arguments to other functions (next week)
  – Because sometimes they are convenient
  – But not a big deal: could define them yourself
Excitement ahead…

Learn some deep truths about “what is really going on”
  – Using much more syntactic sugar than we realized

• Every val-binding and function-binding uses pattern-matching

• Every function in ML takes exactly one argument

First need to extend our definition of pattern-matching…
Each-of types

So far have used pattern-matching for one of types because we *needed* a way to access the values.

Pattern matching also works for records and tuples:
- The pattern \((x_1, \ldots, x_n)\)
  matches the tuple value \((v_1, \ldots, v_n)\)
- The pattern \(\{f_1=x_1, \ldots, f_n=x_n\}\)
  matches the record value \(\{f_1=v_1, \ldots, f_n=v_n\}\)
  (and fields can be reordered)
Example

This is poor style, but based on what I told you so far, the only way to use patterns
  - Works but poor style to have one-branch cases

```haskell
fun sum_triple triple =
    case triple of
        (x, y, z) => x + y + z

fun full_name r =
    case r of
        {first=x, middle=y, last=z} =>
            x ^ " " ^ y ^ " " ^ z
```
Val-binding patterns

• New feature: A val-binding can use a pattern, not just a variable
  – (Turns out variables are just one kind of pattern, so we just
told you a half-truth in Lecture 1)

\[
\text{val } p = e
\]

• Great for getting (all) pieces out of an each-of type
  – Can also get only parts out (not shown here)

• Usually poor style to put a constructor pattern in a val-binding
  – Tests for the one variant and raises an exception if a different
one is there (like \texttt{hd}, \texttt{tl}, and \texttt{valOf})
Better example

This is okay style

– Though we will improve it again next
– Semantically identical to one-branch case expressions

```ml
fun sum_triple triple =  
  let val (x, y, z) = triple  
  in  
    x + y + z  
  end

fun full_name r =  
  let val {first=x, middle=y, last=z} = r  
  in  
    x ^ " " ^ y ^ " " ^ z  
  end
```
Function-argument patterns

A function argument can also be a pattern
   – Match against the argument in a function call

\[
\text{fun } f \ p = e
\]

Examples (great style!):

\[
\text{fun sum_triple } \ (x, y, z) = \\
x + y + z
\]

\[
\text{fun full_name } \{\text{first}=x, \text{middle}=y, \text{last}=z\} = \\
x ^ " " ^ y ^ " " ^ z
\]
A new way to go

• For Homework 2:
  – Do not use the # character
  – Do not need to write down any explicit types
Hmm

A function that takes one triple of type `int*int*int` and returns an `int` that is their sum:

```
fun sum_triple (x, y, z) =
  x + y + z
```

A function that takes three `int` arguments and returns an `int` that is their sum:

```
fun sum_triple (x, y, z) =
  x + y + z
```

See the difference? (Me neither.) 😊
The truth about functions

- In ML, every function takes exactly one argument (*)

- What we call multi-argument functions are just functions taking one tuple argument, implemented with a tuple pattern in the function binding
  - Elegant and flexible language design

- Enables cute and useful things you cannot do in Java, e.g.,

  ```ml
  fun rotate_left (x, y, z) = (y, z, x)
  fun rotate_right t = rotate_left (rotate_left t)
  ```

  * “Zero arguments” is the unit pattern () matching the unit value ()