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

• 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

\[
(* \text{ use the studen\_num and ignore other fields unless the student\_num is } ~1 *)
\]

\[
\{ \text{ student\_num : int,} \\
\quad \text{ first} : \text{ string,} \\
\quad \text{ middle} : \text{ string option,} \\
\quad \text{ last} : \text{ string } \}
\]
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:

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

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

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

Not surprising:
Functions over recursive datatypes are usually recursive

```ml
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 \( t_i \to t \)
- \( C_i \ v \) 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))
```

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`

```plaintext
def 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)

```haskell
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

```
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!):

\[ \text{fun } \text{sum_triple } (x, y, z) = x + y + z \]
\[ \text{fun } \text{full_name } \{ \text{first}=x, \text{middle}=y, \text{last}=z \} = x ^ " " ^ y ^ " " ^ z \]
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 \texttt{int*int*int} and returns an \texttt{int} that is their sum:

\begin{verbatim}
fun sum_triple (x, y, z) =
  x + y + z
\end{verbatim}

A function that takes three \texttt{int} arguments and returns an \texttt{int} that is their sum

\begin{verbatim}
fun sum_triple (x, y, z) =
  x + y + z
\end{verbatim}

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 ()