Variants

Prof. Clarkson
Fall 2016

Today's music: Union by The Black Eyed Peas (feat. Sting)
Review

Previously in 3110:
• User-defined data types: records, tuples, variants
• Built-in data types: lists, options
• A type used in the List module: association lists

Today:
• Type synonyms
• More about variants
• Exceptions
**Variants vs. records vs. tuples**

<table>
<thead>
<tr>
<th></th>
<th>Define</th>
<th>Build</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant</td>
<td><code>type</code></td>
<td>Constructor name</td>
<td>Pattern matching</td>
</tr>
</tbody>
</table>
| Record | `type`   | Record expression with `{...}` | Pattern matching  
OR field selection with dot operator . |
| Tuple  | N/A      | Tuple expression with `(...)` | Pattern matching  
OR `fst` or `snd` |

- **Variants:** one-of types *aka* sum types
- **Records, tuples:** each-of types *aka* product types
Question

Which of the following would be better represented with records rather than variants?

A. *Coins*, which can be pennies, nickels, dimes, or quarters
B. *Students*, who have names and id numbers
C. A *dessert*, which has a sauce, a creamy component, and a crunchy component
D. A and C
E. B and C
Question

Which of the following would be better represented with records rather than variants?

A. Coins, which can be pennies, nickels, dimes, or quarters
B. Students, who have names and NetIDs
C. A dessert, which has a sauce, a creamy component, and a crunchy component
D. A and C
E. B and C
TYPE SYNONYMS
Type synonyms

Syntax: `type id = t`

- Anywhere you write `t`, you can also write `id`
- The two names are *synonymous*

e.g.

```plaintext
type point   = float * float
type vector  = float list
type matrix  = float list list
```
Type synonyms

type point = float*float

let getx : point -> float =
  fun (x,_) -> x

let pt : point = (1.,2.)
let floatpair : float*float = (1.,3.)

let one  = getx pt
let one' = getx floatpair
Recall: Variants

\texttt{type day} = \texttt{Sun} \mid \texttt{Mon} \mid \texttt{Tue} \mid \texttt{Wed} \\
\quad \mid \texttt{Thu} \mid \texttt{Fri} \mid \texttt{Sat}

\texttt{type ptype} = \texttt{TNormal} \mid \texttt{TFire} \mid \texttt{TWater}

\texttt{type peff} = \texttt{ENormal} \mid \texttt{ENotVery} \mid \texttt{Esuper}

So far, just enumerated sets of values
But they can do much more...
Variants that carry data

```haskell
type shape =
  | Point  of point
  | Circle of point * float (* center and radius *)
  | Rect   of point * point (* lower-left and upper-right corners *)

let area = function
  | Point _  -> 0.0
  | Circle (_,r)  -> pi *. (r ** 2.0)
  | Rect ((x1,y1),(x2,y2))  ->
    let w = x2 -. x1 in
    let h = y2 -. y1 in
    w *. h
```
Variants that carry data

define type shape =
  | Point \textbf{of} point
  | Circle \textbf{of} point * float
  | Rect \textbf{of} point * point

let center = \textbf{function}
  | Point p -> p
  | Circle (p,\_\_) -> p
  | Rect ((x1,y1),(x2,y2)) ->
    ((x2 -. x1) /.
     \_\_. 2.0,
     (y2 -. y1) /.
     \_\_. 2.0)
Variants that carry data

type shape =
| Point of point
| Circle of point * float
| Rect of point * point

Every value of type shape is made from exactly one of the constructors and contains:
• a tag for which constructor it is from
• the data carried by that constructor

Called an algebraic data type because it contains product and sum types, aka tagged union
Tagged union

- *Union* because the set of all values of the type is the union of the set of all values of the individual constructors
  
  \[
  \text{type } t = \text{String of string} \\
  \quad \text{\mid Int of int}
  \]

- *Tagged* because possible to determine which underlying set a value came from
  
  \[
  \text{type } t = \text{Left of int} \\
  \quad \text{\mid Right of int}
  \]

- "All for one and one for all":
  - all values of variant, regardless of constructor, have same type
  - any one value of variant built with exactly one constructor, all of which are specified in type definition
Variant types

Type definition syntax:
```
type t = C1 [of t1] | ... | Cn [of tn]
```

A constructor that carries data is *non-constant*

A constructor without data is *constant*

Semantics are straightforward; in slides at end and in notes
Question

Given our shape variant, which function would determine whether a shape is a circle centered at the origin?

```
type shape =
|    Point  of  point
|  Circle  of  point  *  float
|   Rect   of  point  *  point
```

Possible answers on next slide...
type shape = Point of point | Circle of point * float | Rect of point * point

let cato = function
  | Point -> false
  | Circle -> true
  | Rect -> false

let cato = function
  | Point _ | Rect _ -> false
  | Circle (0.,0.), r -> true

let cato c =
  c = Circle ((0.,0.),_)

let cato = function
  | Point p -> false
  | Circle (0.,0.) -> true
  | Rect (ll,ur) -> false

let cato = function
  | Circle ((0.,0.), _) -> true
  | _ -> false
type shape = Point of point | Circle of point * float | Rect of point * point

let cato = function
| Point -> false
| Circle -> true
| Rect -> false

let cato c =
c = Circle ((0.,0.),_)

let cato = function
| Point _ | Rect _ -> false
| Circle (0.,0.), r -> true

let cato = function
| Circle ((0.,0.), _) -> true
| _ -> false
RECURSIVE VARIANTS
Implement lists with variants

type intlist = Nil | Cons of int * intlist

let emp = Nil
let l3 = Cons (3, Nil) (* 3::[] or [3]*)
let l123 = Cons(1, Cons(2, l3)) (* [1;2;3] *)

let rec sum (l:intlist) =
  match l with
  | Nil -> 0
  | Cons(h,t) -> h + sum t
Implement lists with variants

```ocaml
let rec length = function
  | Nil -> 0
  | Cons (_, t) -> 1 + length t
(* length : intlist -> int *)

let empty = function
  | Nil -> true
  | Cons _ -> false
(* empty: intlist -> bool *)
```
PARAMETERIZED VARIANTS
Lists of any type

• **Have:** lists of ints
• **Want:** lists of ints, lists of strings, lists of pairs, lists of records that themselves contain lists of pairs, ...

**Non-solution:** copy code

```plaintext
type stringlist = SNil | SCons of string * stringlist
let empty = function
    | SNil -> true
    | SCons _ -> false
```
Lists of any type

Solution: parameterize types on other types

type 'a mylist = Nil | Cons of 'a * 'a mylist

let l3 = Cons (3, Nil) (* [3] *)
let lhi = Cons ("hi", Nil) (* ["hi"] *)
Lists of any type

type 'a mylist =
   | Nil
   | Cons of 'a * 'a mylist

mylist is not a type but a type constructor: takes a type as input and returns a type
• int mylist
• string mylist
• (int*string) mylist
• ...

Functions on parameterized variants

```plaintext
let rec length = function
    | Nil -> 0
    | Cons (_,t) -> 1 + length t
(* length : 'a mylist -> int *)

let empty = function
    | Nil -> true
    | Cons _ -> false
(* empty: 'a mylist -> bool *)
```

code stays the same; only the types change
Parametric polymorphism

- \textit{poly} = many, \textit{morph} = form
- write function that works for many arguments regardless of their type
- closely related to Java generics, related to C++ template instantiation, ...
THE POWER OF VARIANTS
Lists are just variants

OCaml effectively codes up lists as variants:

```ocaml
type 'a list = [] | :: of 'a * 'a list
```

- `list` is a type constructor parameterized on type variable `'a`
- `[]` and `::` are constructors
- Just a bit of syntactic magic in the compiler to use `[]` and `::` instead of alphabetic identifiers
Options are just variants

OCaml effectively codes up options as variants:

```ocaml
type 'a option = None | Some of 'a
```

- **option** is a type constructor parameterized on type variable 'a
- **None** and **Some** are constructors
Exceptions are (mostly) just variants

OCaml effectively codes up exceptions as slightly strange variants:

```ocaml
type exn
exception MyNewException of string
```

- Type `exn` is an *extensible* variant that may have new constructors added after its original definition.
- Raise exceptions with `raise e`, where `e` is a value of type `exn`.
- Handle exceptions with pattern matching, just like you would process any variant.
Upcoming events

• [now] Questions about lecture and course logistics have priority over questions about content of A1
• [today] iclicker and recitation attendance begin counting toward grade; eventually you'll be able to check your iclicker in Blackboard and your recitation in CMS but not yet
• [Wed] A1 due

This is all for one and one for all.

THIS IS 3110
SYNTAX AND SEMANTICS
Non-constant variant expressions

Syntax: \( C \ e \)

Evaluation:
\[
\text{if } e \implies v \text{ then } C \ e \implies C \ v
\]

Type checking:
\[
C \ e : t
\]
\[
\text{if } t = \ldots \mid C \text{ of } t' \mid \ldots
\]
\[
\text{and } e : t'
\]
Constant variant expressions

Syntax: \( C \)

Evaluation: already a value

Type checking:
\[ C : t \]
\[ if t = \ldots \mid C \mid \ldots \]
Pattern matching

• Match against constant variants: \texttt{C}
  (Already had this pattern from last lecture)

• Match against non-constant variants: \texttt{C p}
  (new today)