CSE341: Programming Languages

Lecture 4
Records ("each of"), Datatypes ("one of"), Case Expressions

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Fall 2011

Review

- Done: functions, tuples, lists, local bindings, options
- Done: syntax vs. semantics, environments, mutation-free
- Today: Focus on *compound types*
  - New feature: *records*
    - New concept: *syntactic sugar* (tuples are records)
  - New features: *datatypes, constructors, case expressions*

How to build bigger types

- Already know:
  - Have various *base types* like **`int bool unit char`**
  - Ways to build (nested) *compound types*: tuples, lists, options

- Today: more ways to build compound types

- First: 3 most important type building blocks in *any* language
  - "Each of": A **`t`** value contains *values of each of* **`t1 t2 … tn`**
  - "One of": A **`t`** value contains *values of one of* **`t1 t2 … tn`**
  - "Self reference": A **`t`** value can refer to other **`t`** values

  Remarkable: A lot of data can be described with just these building blocks

  Note: These are not the common names for these concepts

Examples

- Tuples build each-of types
  - **`int * bool`** contains an **`int`** *and* a **`bool`**
- Options build one-of types
  - **`int option`** contains an **`int`** *or* it contains no data
- Lists use all three building blocks
  - **`int list`** contains an **`int`** *and* another **`int list`** *or* it contains no data
- And of course we can nest compound types
  - **`((int * int) option) * (int list list)) option`**

Rest of today

- Another way to build each-of types in ML
  - Records: have named fields
  - Connection to tuples and idea of syntactic sugar

- A way to build and use our own one-of types in ML
  - For example, a type that contains and **`int`** or a **`string`**
  - Will lead to *pattern-matching* (more next lecture), one of ML's coolest and strangest-to-Java-programmers features
  - How OOP does one-of types discussed later in course

Records

Record values have fields (any name) holding values

```
{f1 = v1, …, fn = vn}
```

Record types have fields (and name) holding types

```
{f1 : t1, …, fn : tn}
```

The order of fields in a record value or type never matters

- REPL alphabetizes fields just for consistency

Building records:

```
{f1 = e1, …, fn = en}
```

Accessing components:

```
#myfieldname e
```

(Evaluation rules and type-checking as expected)

Example

```
{name = "Amelia", id = 41123 - 12}
```

Evaluates to

```
{id = 41111, name = "Amelia"}
```

And has type

```
{id : int, name : string}
```

If some expression such as a variable **x** has this type, then get fields with:

```
#id x      #name x
```

Note we didn't have to declare any record types

- The same program could also make a **{id=true,ego=false}** of type **{id:bool,ego:bool}**

By name vs. by position

- Little difference between **`(4,7,9)`** and **`{f=4,g=7,h=9}`**
  - Tuples a little shorter
  - Records a little easier to remember "what is where"
  - Generally a matter of taste, but for many (6? 8? 12?) fields, a record is usually a better choice

- A common decision for a construct's syntax is whether to refer to things *by position* (as in tuples) or *by some (field) name* (as with records)
  - A common hybrid is like with Java method arguments (and ML functions as used so far):
    - Caller uses *position*
    - Callee uses *variables*
    - Could totally do it differently; some languages have

The truth about tuples

Last week we gave tuples syntax, type-checking rules, and evaluation rules

But we could have done this instead:

- Tuple syntax is just a different way to write certain records
- **`(e1,…,en)`** is another way of writing **`{1=e1,…,n=en}`**
- **`t1*…*tn`** is another way of writing **`{1:t1,…,n:tn}`**
- In other words, records with field names 1, 2, …

In fact, this is how ML actually defines tuples

- Other than special syntax in programs and printing, they don't exist
- You really can write **`{1=4,2=7,3=9}`**, but it's bad style

Syntactic sugar

"Tuples are just syntactic sugar for
records with fields named 1, 2, … n"

- *Syntactic*: Can describe the semantics entirely by the corresponding record syntax

- *Sugar*: They make the language sweeter ☺

Will see many more examples of syntactic sugar
- They simplify *understanding* the language
- They simplify *implementing* the language

Why? Because there are fewer semantics to worry about even though we have the syntactic convenience of tuples

Datatype bindings

A “strange” (?) and totally awesome (!) way to make one-of types:

– A **`datatype`** binding

```
datatype mytype = TwoInts of int * int
                | Str of string
                | Pizza
```

- Adds a new type **`mytype`** to the environment
- Adds *constructors* to the environment: **`TwoInts`**, **`Str`**, and **`Pizza`**
- A constructor is (among other things), a function that makes values of the new type (or is a value of the new type):
  - **`TwoInts : int * int -> mytype`**
  - **`Str : string -> mytype`**
  - **`Pizza : mytype`**

The values we make

```
datatype mytype = TwoInts of int * int
                | Str of string
                | Pizza
```

- Any value of type **`mytype`** is made from *one of* the constructors
- The value contains:
  - A “tag” for “which constructor” (e.g., **`TwoInts`**)
  - The corresponding data (e.g., **`(7,9)`**)
- Examples:
  - **`TwoInts(3+4,5+4)`** evaluates to **`TwoInts(7,9)`**
  - **`Str(if true then "hi" else "bye")`** evaluates to **`Str("hi")`**
  - **`Pizza`** is a value

Using them

So we know how to *build* datatype values; need to *access* them

There are *two* aspects to accessing a datatype value

1. Check what *variant* it is (what constructor made it)
2. Extract the *data* (if that variant has any)

Notice how our other one-of types used functions for this:

- **`null`** and **`isSome`** check variants
- **`hd`**, **`tl`**, and **`valOf`** extract data (raise exception on wrong variant)

ML *could* have done the same for datatype bindings

- For example, functions like "isStr" and "getStrData"
- Instead it did something better

Case

ML combines the two aspects of accessing a one-of value with a *case expression* and *pattern-matching*

- Pattern-matching much more general/powerful (lecture 5)

Example:

```
fun f x = (* f has type mytype -> int *)
    case x of
        Pizza => 3
      | TwoInts(i1,i2) => i1+i2
      | Str s => String.size s
```

- A multi-branch conditional to pick branch based on variant
- Extracts data and binds to variables local to that branch
- Type-checking: all branches must have same type
- Evaluation: evaluate between case … of and right branch

Patterns

In general the syntax is:

```
case e0 of
      p1 => e1
    | p2 => e2
      …
    | pn => en
```

For today, each *pattern* is a constructor name followed by the right number of variables (i.e., **C** or **C x** or **C(x,y)** or …)

- Syntactically most patterns (all today) look like expressions
- But patterns are not expressions
  - We do not evaluate them
  - We see if the result of **e0** *matches* them

Why this way is better

0. You can use pattern-matching to write your own testing and data-extractions functions if you must
   - But don't do that on your homework

1. You can't forget a case (inexhaustive pattern-match a warning)
2. You can't duplicate a case (a type-checking error)
3. You won't forget to test the variant correctly and get an exception (like **`hd []`**)
4. Pattern-matching can be generalized and made more powerful, leading to elegant and concise code

Useful examples

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

- Enumerations, including carrying other data

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

- Alternate ways of representing data about things (or people ☺)

```
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

```
(* 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 it 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:

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

Expression Trees

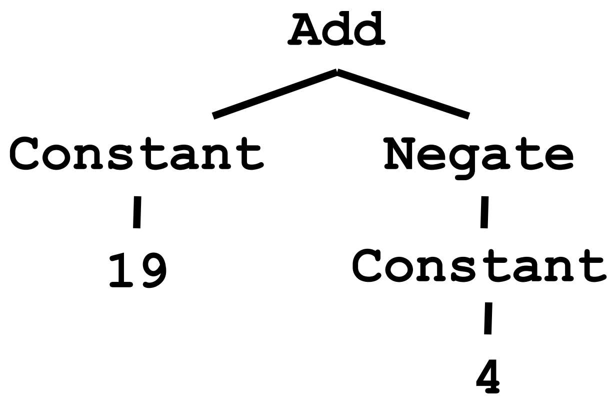
A more exciting (?) example of a datatype, using self-reference

```
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:



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)
```