PAUL G. ALLEN SCHOOL OF COMPUTER SCIENCE & ENGINEERING

CSE341: Programming Languages

Lecture 4
Records, Datatypes, Case Expressions

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Five different things

1. Syntax: How do you write language constructs?
2. Semantics: What do programs mean? (Evaluation rules)
3. Idioms: What are typical patterns for using language features to express your computation?
4. Libraries: What facilities does the language (or a well-known project) provide "standard"? (E.g., file access, data structures)
5. Tools: What do language implementations provide to make your job easier? (E.g., REPL, debugger, code formatter, …)
   – Not actually part of the language

These are 5 separate issues
- In practice, all are essential for good programmers
- Many people confuse them, but shouldn't

Our Focus

This course focuses on semantics and idioms

- Syntax is usually uninteresting
  - A fact to learn, like "The American Civil War ended in 1865"
  - People obsess over subjective preferences
- Libraries and tools crucial, but often learn new ones "on the job"
  - We are learning semantics and how to use that knowledge to understand all software and employ appropriate idioms
  - By avoiding most libraries/tools, our languages may look "silly" but so would *any* language used this way

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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
- Coming soon: 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 this Lecture

- 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 an **`int`** or a **`string`**
  - Will lead to *pattern-matching*, one of ML's coolest and strangest-to-Java-programmers features
- Later in course: How OOP does one-of types
  - Key contrast with procedural and functional programming

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 = "Matai", id = 4 - 3}
```

Evaluates to

```
{id = 1, name = "Matai"}
```

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 did not 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

Previous lecture 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

Another example we saw: **andalso** and **orelse** vs. **if then else**

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 the 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 do not do that on your homework

1. You cannot forget a case (inexhaustive pattern-match warning)
2. You cannot duplicate a case (a type-checking error)
3. You will not 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