CSE 341:
Programming Languages

Spring 2007
Lecture 4 — user-defined types

Where are we

- Features so far: functions, tuples, lists, options, local bindings
- Concepts so far: syntax vs. semantics, environments
- Today's features: record types, datatypes, pattern-matching
- Today's concepts: types, constructors/deconstructors, case-coverage

Base types and compound types

Languages typically provide a small number of "built-in" types and ways to build compound types out of simpler ones:

- Base types examples: `int`, `bool`
- Type builder examples: tuples, lists, *records*

Base types *clutter* a language definition? better to make them *libraries* when possible?

- ML does this to a remarkable extent (e.g., we will soon define away `bool` and conditionals)

Good to let programmers bind types to type names, just like we bind values to variables.

Compound-type flavors

Conceptually, just a few ways to build compound types:

1. "Each-of": A `t` contains a `t1` *and* a `t2`
2. "One-of": A `t` contains a `t1` *or* a `t2`
3. "Self-reference": The definition of `t` may refer to `t`

Examples:

- `int * bool`
- `int option`
- `int list`

Fact: A *lot* of data can be described this way.
Convenient to think of as trees.

(optional) jargon: Product types, sum types, recursive types

User-defined types

There are many reasons to define your own types:

1. Using a tuple with 12 fields is incomprehensible
2. Writing down large types is unpleasant, error-prone; computers can help
3. Large programs can use *abstract types* to be robust to change
   - A couple weeks ahead
4. So the language doesn't have to "build in" lists and options and . . . that aren't always needed

Datatype

One-of types are less similar across languages

- We'll discuss OO's approach to one-of in a few weeks

In ML, we use make a *new type* with a `datatype` binding, e.g.:

```
datatype exp = Const of int
     | Negate of exp
     | Add of exp * exp
     | Mul of exp * exp
```

Semantics: Extend the environment with four *constructors* (in part, functions/constants that produce values of type `exp`)

```
val e = Add(Const(42),Negate(Mul(Const(7),Const(6))))
```

So we have a way to build them... what's missing?

The old way

For lists, we had a way to:

- Test which *variant* a value was (`null`)
- Extract the values from *value-carrying* variants (`hd`/`tl`)
  - Makes no sense if you have the *wrong* variant

What would this look like for `exp`?

The new way

Rather than add *variant-tests* and *variant-deconstructors*, ML has a *case expression* that uses *pattern-matching*.

In its simplest form, case has one pattern for each constructor in a dataype and binds one variable for each value carried. Example:

```
fun eval e =
    case e of
        Const i => i
      | Negate e2 => ~ (eval e2)
      | Add(e1,e2) => (eval e1) + (eval e2)
      | Mul(e1,e2) => (eval e1) * (eval e2)

val z = eval Add(Const(42),Negate(Mul(Const(7),Const(6))))
```

What are the typing rules?
What are the evaluation rules?

Type-checking case

In addition to binding local variables and requiring branches to have the same type, the typing rules for case prevent some run-time errors:

- Exhaustiveness: No test can "fail" (a warning)
- Redundancy: No test can be "impossible" (an error)

So far, case gives us what we *need* to use datatypes:

- A (combined) way to test variants and extract values (deconstruct)
- Powerful enough to define our own tests and deconstructors

In fact, pattern-matching is far more general and elegant:

- Can use it for datatypes already in the top-level environment
- Can use it for *any* type (later)
- Can have deep patterns (later)