CSE 341: Programming Languages

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Lecture 12— Type Inference, Parametric Polymorphism, Type Constructors

Today

- We have learned an interesting subset of the ML expression language
- But we have been really informal about some aspects of the type system:
  - Type inference (what types do bindings implicitly have)
  - Type variables (what do `'a` and `'b` really mean)
  - Type constructors (why is `int list` a type but not `list`)
- Note: Type inference and parametric polymorphism are separate concepts that end up intertwined in ML. A different language could have one or the other.

Type Inference

Some languages are untyped or dynamically typed.

ML is *statically typed*; every binding has one type, determined during type-checking (compile-time).

ML is *implicitly typed*; ignoring a few things like "dot-dot-dot patterns" programmers never need to write the types of bindings.

The type-inference question: Given a program without explicit types, produce types for all bindings such that the program type-checks, or reject (only) if it is impossible.

Whether type inference is easy, hard, or impossible depends on details of the type system: Making it more or less powerful (i.e., more programs typecheck) may make inference easier or harder.

ML Type Inference

- Determine types of bindings in order (earlier first) (except for mutual recursion)
- For each `val` or `fun` binding, analyze the binding to determine necessary facts about its type.
- Afterward, use *type variables* (e.g., `'a`) for any unconstrained types in function arguments or results.
- Some extra details for type variables and references we'll mention later.

Amazing fact: For the ML type system, "going in order" this way never causes unnecessary rejection.

Example 1

```
fun f x =
   let val (y,z) = x in
       (Math.abs y) + z
   end
```

Example 2

```
fun sum lst =
   case lst of
     [] => 0
   | hd::tl => hd + (sum tl)
```

Example 3

```
fun compose (f,g,x) = f (g x)
```

Comments on ML type inference

- If we had subtyping, the "equality constraints" we generated would be unnecessarily restrictive.
- If we did not have type variables, we would not be able to give a type to `compose` until we saw how it was used.
  - But type variables are useful regardless of inference.
- Inference is why `let val x = e1 in e2 end` is not really sugar for `(fn x => e2) e1` because the latter gives a type error if `e2` contains `x 0` and `x "foo"`, even if `e1` if `fn y => y`.
  - Don't worry if that doesn't make sense.

Parametric polymorphism

Fancy words for "forall-types". Coming to next version of Java, C#, VB, etc. Sometimes called generics. A bit like C++ templates if C++ didn't have operator-overloading.

In principle, just two new kinds of types:

```
tv ::= 'a | 'b | ...
t  ::= int | string | bool | t1->t2 | {l1:t1, ..., ln:tn}
     | dtname |  tv | forall tv. t
```

Given an expression of type `forall 'tv. t`, we can *instantiate* it at type `t2` to get an expression of type "`t` with `'tv` replaced by `t2`"

Example: We can instantiate
`forall 'a. forall 'b. ('a * 'b) -> ('b * 'a)` with `string` for `'a` and `int->int` for `'b` to get
`(string * (int->int)) -> ((int->int) * string)`

ML-style polymorphism

The ML type system is actually more restrictive:

- "`forall`" must appear "all the way on the outside-left"
- So it's implicit; no way to write the words "for all"

Example: `('a * 'b) -> ('b * 'a)` means

`forall 'a. forall 'b. ('a * 'b) -> ('b * 'a)`

Non-example: There's no way to have a type like

`(forall 'a. 'a -> int) -> int`

Easy to express this restriction syntactically:

```
tv ::= 'a | 'b | ...
s  ::= int | string | bool | t1->t2 | {l1:t1, ..., ln:tn}
    | dtname | tv
t  ::= s | forall tv. t
```

Versus Subtyping

Compare

```
fun swap (x,y) = (y,x) (* ('a * 'b) -> ('b * 'a) *)
```

with

```
class Pair { Object x; Object y; ... }
Pair swap(Pair pr) { return new Pair(pr.y, pr.x); }
```

ML wins in two ways (for this example):

- Caller instantiates types, so doesn't need to cast result
- Callee cannot return a pair of any two objects.

Containers

Parametric polymorphism (forall types) are also the right thing for containers (lists, sets, hashtables, etc.) where elements have the same type.

Example: ML lists

```
val :: : ('a * ('a list)) -> 'a list (* infix is syntax *)
val map : (('a -> 'b) * ('a list)) -> 'b list
val sum : int list -> int
val fold : ('a * 'b -> 'b) -> ('a list) -> 'b
```

`list` is not a type; if `t` is a type, then `t list` is a type.

User-defined type constructors

Language-design: don't provide a fixed set of a useful thing.

Let programmers declare type constructors.

Examples:

```
datatype 'a non_mt_list = One of 'a
                        | More of 'a * ('a non_mt_list)
datatype 'a rope = Empty
                 | Cons of 'a * ('a rope)
                 | Rope of ('a rope) * ('a rope)
```

You can have multiple type-parameters (not shown here).

And now, finally, *everything* about lists is syntactic sugar!

One last thing – not on the test

Polymorphism and mutation can be a dangerous combination.

```
val x = ref [] (* 'a list ref *)
val _ = x := ["hi"]  (* instantiate 'a with string *)
val _ = (hd(!x)) + 7 (* instantiate 'a with int -- bad!! *)
```

Roughly, ML ensures the `t` in `t ref` has no new type variables.

But they do it with a non-obvious way: function applications (such as `ref []`) cannot get polymorphic types; user specifies (e.g., `int list ref`)