CS558 Programming Languages

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Lecture 7b

Andrew Tolmach
Portland State University

Dynamic Type Checking

- Static type checking offers the great advantage of catching errors early
- And it generally supports more efficient execution
- So why ever consider dynamic type checking?
- Simplicity. For short or simple programs, it's nice to avoid the need to declare the types of identifiers
- Flexibility. Static type checking is inherently more conservative about what programs it allows.

Conservative Typing

- For example, suppose + is defined on both strings and numbers (but not mixtures of the two). Then

```
(if b then "a" else 2) + (if b then "c" else 3)
```

will never cause a run-time type error, but it will still be rejected by a static type system

- Dynamic typing allows container data structures to contain mixtures of values of arbitrary types, e.g.

```
List(2, true, 3.14)
```

Type Inference

- Some statically typed languages, like ML (and to a lesser extent Scala), offer alternative ways to regain the flexibility of dynamic typing, via type inference and polymorphism.
- Type inference works like this:
  - The types of identifiers are automatically inferred from the way they are used
  - The programmer is no longer required to declare the types of identifiers (although this is still permitted)
  - Method requires that the types of operators and literals is known

Inference Examples

```
(let f (fun (x) (+ x 2))
     (@ f y))
```

The type of `x` must be `int` because it is used as an arg to `+`. So the type of `f` must be `int → int` (i.e. the type of functions that expect an `int` argument and return an `int` result), and `y` must be an `int`.

```
(let f (fun (x) (cons x nil))
     (@ f true))
```

Suppose `x` has some type `t`. Then the type of `f` must be `t → (list t)`. Since `f` is applied to a `bool`, we must have `t = bool`.

For the moment, we assume that `f` must be given a unique monomorphic type; we will relax this later…

Systematic Inference

- Here's a harder example:

```
(let f (fun (x) (if x p q))
     (+ 1 (@ f r)))
```

- Can only infer types by looking at both the function's body and its application
- In general, we can solve the inference task by extracting a collection of typing constraints from the program's AST, and then finding a simultaneous solution for the constraints using unification
- Extracted constraints tell us how types must be related if we are to be able to find a typing derivation. Each node generates one or more constraints

Rules for First-class Functions

- To handle this example, we'll need some extra typing rules:

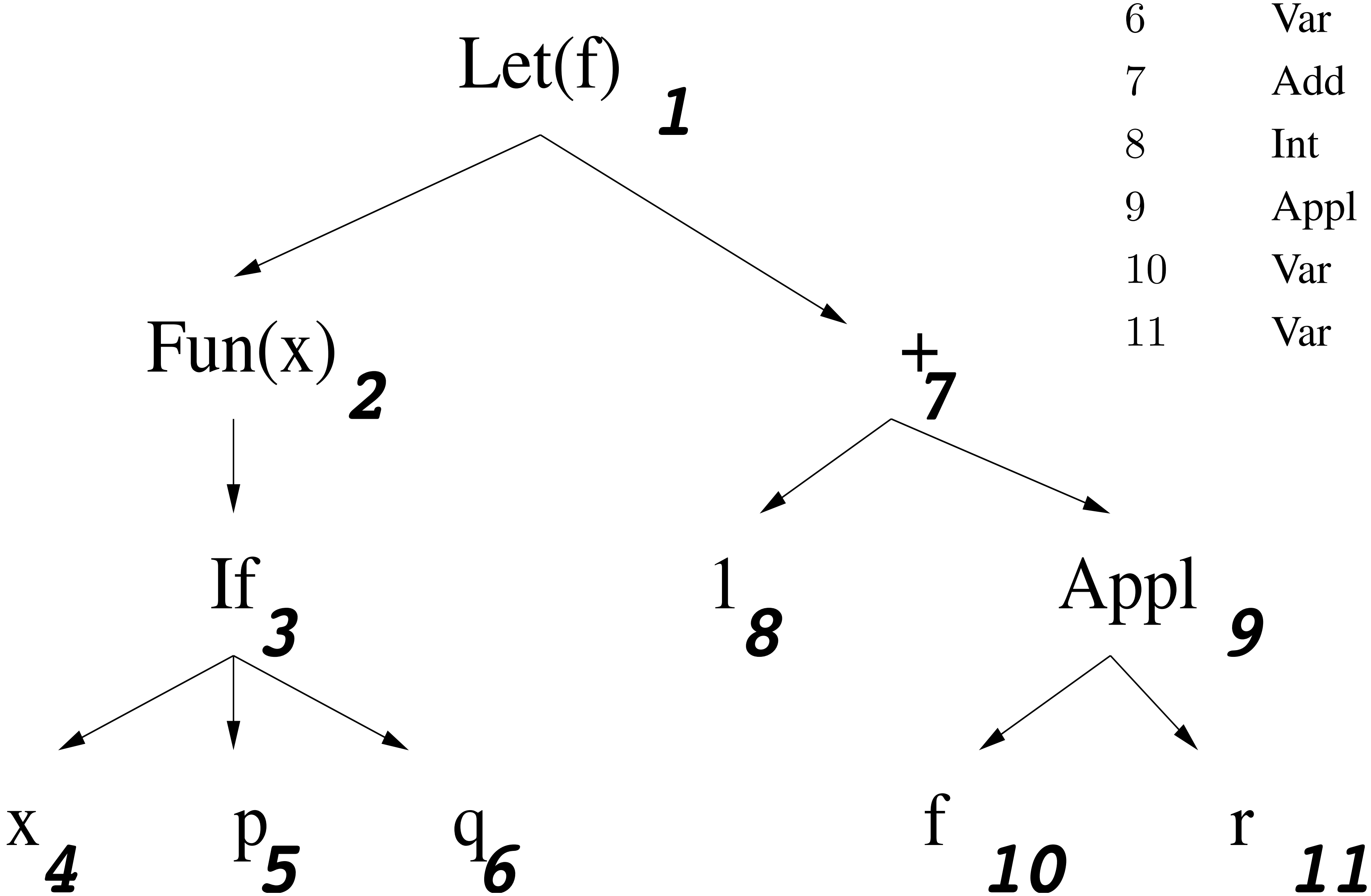
$$\frac{TE + \{x \mapsto t_1\} \vdash e : t_2}{TE \vdash \texttt{(fun (}x\texttt{)}\ e\texttt{)} : t_1 \to t_2}\ \text{(Fn)}$$

$$\frac{TE \vdash e_1 : t_1 \to t_2 \quad TE \vdash e_2 : t_1}{TE \vdash \texttt{(@}\ e_1\ e_2\texttt{)} : t_2}\ \text{(Appl)}$$

Inference Example

Solution : $t_1 = t_7 = t_8 = t_9 = t_3 = t_5 = t_p = t_6 = t_q = \texttt{int}$
$t_4 = t_x = t_{11} = t_r = \texttt{bool}$ $\quad t_2 = t_f = t_{10} = \texttt{bool} \rightarrow \texttt{int}$

Node	*Rule*	*Constraints*	
1	Let	$t_f = t_2$	$t_1 = t_7$
2	Fun	$t_2 = t_x \rightarrow t_3$	
3	If	$t_4 = \texttt{bool}$	$t_3 = t_5 = t_6$
4	Var	$t_4 = t_x$	
5	Var	$t_5 = t_p$	
6	Var	$t_5 = t_q$	
7	Add	$t_7 = t_8 = t_9 = \texttt{int}$	
8	Int	$t_8 = \texttt{int}$	
9	Appl	$t_{10} = t_{11} \rightarrow t_9$	
10	Var	$t_{10} = t_f$	
11	Var	$t_{11} = t_r$	



Drawbacks of Inference

- Consider this variant example:

```
(let f (fun (x) (if x p false)
     (+ 1 (@ f r)))
```

- Now the body of `f` returns type `bool`, but it is used in a context expecting an `int`.
- The corresponding extracted constraints will be inconsistent; no solution can be found. Can report a type error to the programmer.
- But which is wrong, the definition of `f` or the use? No good way to associate the error message with a single program point.

Polymorphism

- Consider

```
(let snd (fun (l) (head (tail l)))
     (@ snd (cons 1 (cons 2 (cons 3 nil)))))
```

- By extracting constraints and solving, we will get

```
snd : (list int) → int
```

Same definition!

- We could also write

```
(let snd (fun (l) (head (tail l)))
     (@ snd (cons true (cons false (cons true nil)))))
```

- And get

```
snd : (list bool) → bool
```

Polymorphism (2)

- So why can't we write something like this?

```
(let snd (fun (l) (head (tail l)))
   (block
     (@ snd (cons 1 (cons 2 (cons 3 nil))))
     (@ snd (cons true (cons false (cons true nil))))))
```

- We can, by treating the type of `snd` as polymorphic

```
snd : (list t) → t
```

- Here `t` is an unconstrained type variable

Inferring Polymorphism

- In fact, if we extract constraints and solve just for the definition `(fun l (head (tail l)))` without considering its uses, we will end up with exactly the type `(list t)` → `t`

- We can assign this polymorphic type to `snd` allowing it to be used multiple times, each with a different instance of `t` (e.g. with `t = bool` or `t = int`).

- By default, languages like ML infer the most polymorphic possible type for every function
  - This is the natural result of the inference process we've described

Parametric Polymorphism

- We can think of these polymorphic types as being universally quantified over their type variables and instantiated at use sites

```
let snd : ∀t. list t -> t  = …
in snd {bool} (true::false::nil);
   snd {int} (1::2::nil)
```

- This is called parametric polymorphism because the function definition is (implicitly) parameterized by the instantiating type
  - In ML-like languages the quantification and instantiation don't actually appear

Explicit Parametric Polymorphism

- Java generics and Scala type parameterization are also a form a parametric polymorphism, in which type abstraction and instantiation are (mostly) explicit

```scala
def snd[A](l: List[A]) : A = l.tail.head
val a = snd[Boolean] (List(true,false))
val b = snd(List(1,2))
```

Scala

- In parametric polymorphism, the behavior of the polymorphic function is the same no matter what the instantiating type is
    - In fact, an ML compiler typically generates just one piece of machine code for each polymorphic function, shared by all instances

Overloading and Ad-hoc Polymorphism

- Most languages provide some form of overloading, where the same function name or operator symbol means different things depending on the types to which it is applied
    - e.g. overloading of arithmetic operators to work on either integers or floats is very common
- Some languages (e.g. Ada, C++) support user-defined overloading, especially useful for user-defined types (e.g. complex numbers)
    - OO languages (e.g. C++,Java) often support method overloading based on argument types
- Overloading is sometimes called ad-hoc polymorphism, because the implementation of the overloaded operator changes based on the argument types

Static vs. Dynamic Overloading

- In most statically-typed languages, overloading is resolved statically; i.e. the compiler selects the right version of the overloaded definition once and for all at compile time.
- Dynamically-typed languages also often overload operators (e.g. + on different kinds of numbers, strings, etc.)
  - Here the right version of the overloaded operator is picked at runtime after checking the (runtime) types of the arguments
  - Of course, the operator might fail altogether if there is no version suitable for the types discovered
- Haskell type classes provide an unusual form of dynamic overloading with a static guarantee that a suitable version exists