Type-checking

- (Static) type-checking can reject a program before it runs to prevent the possibility of some errors
  - A feature of statically typed languages
- Dynamically typed languages do little (none?) such checking
  - So might try to treat a number as a function at run-time
- Will study relative advantages after some Racket
  - Racket, Ruby (and Python, Javascript, …) dynamically typed
- ML (and Java, C#, Scala, C++) is statically typed
  - Every binding has one type, determined “at compile-time”

Implicitly typed

- ML is statically typed
- ML is implicitly typed: rarely need to write down types

Overview

- Will describe ML type inference via several examples
  - General algorithm is a slightly more advanced topic
  - Supporting nested functions also a bit more advanced
- Enough to help you “do type inference in your head”
  - And appreciate it is not magic

Key steps

- Determine types of bindings in order
  - (Except for mutual recursion)
  - So you cannot use later bindings: will not type-check
- For each val or fun binding:
  - Analyze definition for all necessary facts (constraints)
  - Example: If see x > 0, then x must have type int
  - Type error if no way for all facts to hold (over-constrained)
- Afterward, use type variables (e.g., ‘a’) for any unconstrained types
  - Example: An unused argument can have any type
- (Finally, enforce the value restriction, discussed later)
**Very simple example**

After this example, will go much more step-by-step
– Like the automated algorithm does

```plaintext
val x = 42 (* val x : int *)
fun f (y, z, w) = if y (* y must be bool *)
  then x + w (* x must be int *)
  else 0 (* both branches have same type *)
  (* f must return an int
   f must take a bool * int * ANYTHING
   so val f : bool * int * 'a -> int *)
```

**Relation to Polymorphism**

• Central feature of ML type inference: it can infer types with type variables
  – Great for code reuse and understanding functions

• But remember there are two orthogonal concepts
  – Languages can have type inference without type variables
  – Languages can have type variables without type inference

**Key Idea**

• Collect all the facts needed for type-checking

• These facts constrain the type of the function

  • See code and/or reading notes for:
    – Two examples without type variables
    – And one example that does not type-check
    – Then examples for polymorphic functions
      • Nothing changes, just under-constrained: some types can be anything but may still need to be the same as other types

**Two more topics**

• ML type-inference story so far is too lenient
  – Value restriction limits where polymorphic types can occur
  – See why and then what

• ML is in a “sweet spot”
  – Type inference more difficult without polymorphism
  – Type inference more difficult with subtyping

Important to “finish the story” but these topics are:
– A bit more advanced
– A bit less elegant
– Will not be on the exam

**The Problem**

As presented so far, the ML type system is unsound!
– Allows putting a value of type \( \text{t1} \) (e.g., \text{int}) where we expect a value of type \( \text{t2} \) (e.g., \text{string})

A combination of polymorphism and mutation is to blame:

```plaintext
val r = ref \text{NONE} (* val r : 'a option ref *)
val _ = r := \text{SOME "hi"}
val i = 1 + valOf (!r)
```

• Assignment type-checks because \((\text{infix}) := \text{has type} \ 'a \text{ ref} * 'a \text{ -> unit, so instantiate with string}\)
• Dereference type-checks because \(\text{has type} \ 'a \text{ ref} \rightarrow 'a \text{ so instantiate with int}\)
What to do
To restore soundness, need a stricter type system that rejects at least one of these three lines

- And cannot make special rules for reference types because type-checker cannot know the definition of all type synonyms
  - Due to module system

| val x = ref NONE (* val x : 'a option ref *) |
| val _ = x := SOME "hi" |
| val i = 1 + valOf (!r) |

The fix
- Value restriction: a variable-binding can have a polymorphic type only if the expression is a variable or value
  - Function calls like ref NONE are neither
- Else get a warning and unconstrained types are filled in with dummy types (basically unusable)
- Not obvious this suffices to make type system sound, but it does

The downside
As we saw previously, the value restriction can cause problems when it is unnecessary because we are not using mutation

| val pairWithOne = List.map (fn x => (x,1)) |
| (* does not get type 'a list -> ('a*int) list *) |

A local optimum
- Despite the value restriction, ML type inference is elegant and fairly easy to understand
- More difficult without polymorphism
  - What type should length-of-list have?
- More difficult with subtyping
  - Suppose pairs are supertypes of wider tuples
  - Then val (y,z) = x constrains x to have at least two fields, not exactly two fields
  - Depending on details, languages can support this, but types often more difficult to infer and understand
  - Will study subtyping later, but not with type inference