CS 251 Fall 2019
Principles of Programming Languages
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Type Checking and Type Inference

https://cs.wellesley.edu/~cs251/f19/

Type checking

Static:
Can reject a program before it runs to prevent possibility of some errors.

Dynamic:
Little/no static checking.
May try to treat a number as a function during evaluation. Report error then.

Part of language definition,
not an implementation detail.

static types ≠ explicit types

```
fun f x = (* infer val f : int -> int *)
    if x > 3
    then 42
    else x * 2

fun g x = (* report type error *)
    if x > 3
    then true
    else x * 2
```


Type inference

Problem:
- Give every binding/expression a type such that type checking succeeds.
- Fail *if and only if* no solution exists

Implementation:
- Could be a pass before type checker
- Often implemented in type checker

Easy, difficult, or *impossible:*
- Easy: Accept all programs
- Easy: Reject all programs
- Subtle, elegant, and *not magic*: ML

Human type inference...

What is the type of x?

What is the type of f?

```
val x = 42

fun f (y, z, w) =
    if y
    then z + x
    else 0
```

Describe your process.

Next:

- More examples, but:
  - General algorithm is a slightly more advanced topic
  - Supporting nested functions also a bit more advanced
- Enough to "do type inference in your head"
  - And appreciate it is not magic

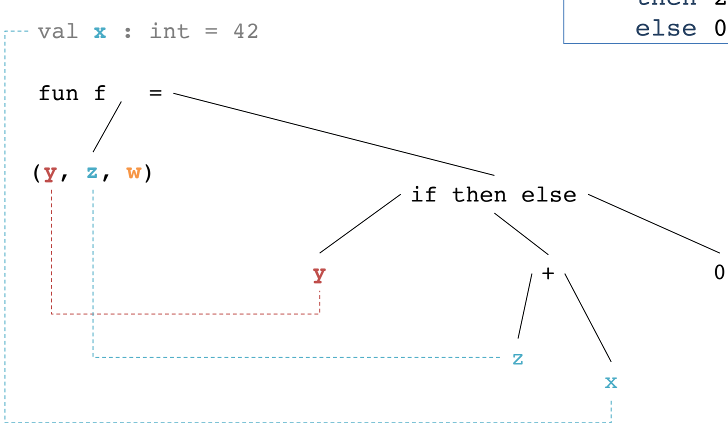
Key steps

1. Determine types of bindings in order
   - Cannot use later bindings.
2. For each `val` or `fun` binding:
   - Analyze definition for all necessary facts (constraints).
     - Example: `x > 0` ⇒ `x : int`
   - Type error if no way for all facts to hold (over-constrained)
3. Use type variables (`'a` …) for any unconstrained types.
   Inference and polymorphism are orthogonal; together = "sweet spot"
4. Enforce the *value restriction*, discussed later.

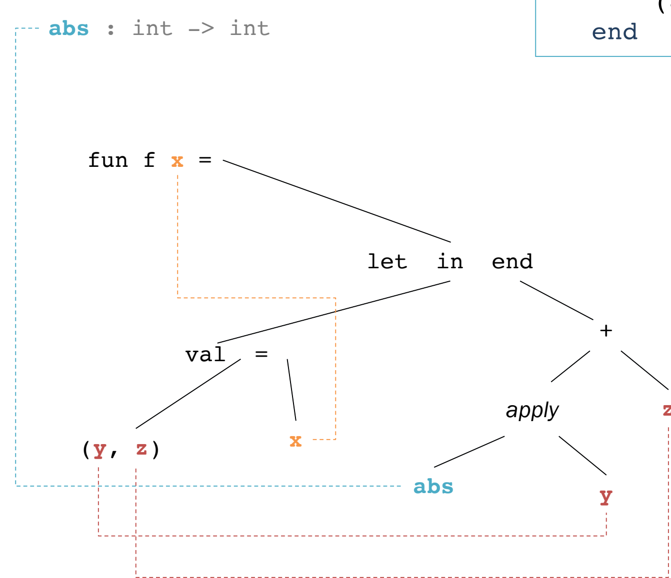
See code examples in inf.sml.


```
val x = 42

fun f (y, z, w) =
    if y
    then z + x
    else 0
```




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



Problem: unsoundness!

Combine polymorphism and **mutation**:

```
val thing = ref NONE (* : 'a option ref *)
val _ = thing := SOME "hi"
val i = 1 + case !thing of NONE => 0 | SOME x => x
```

- Assignment type-checks:
  - `(op:=) :'a ref * 'a -> unit`
  - instantiate **`string`** for **`'a`**
  - use as **`string`** `ref *` **`string`** `-> unit`
- Dereference type-checks:
  - `! : 'a ref -> 'a`
  - instantiate **`int`** for **`'a`**
  - use as **`int`** `ref ->` **`int`**
- **`val i : int = "hi"`**

Solution

Reject at least one of these lines

```
val thing = ref NONE (* : 'a option ref *)
val _ = thing := SOME "hi"
val i = 1 + case !thing of NONE => 0 | SOME x => x
```

Cannot just special-case ref types. Abstract types!

```
signature HIDE = sig
  type 'a hidden
  val make : 'a -> 'a hidden
  val thing : 'a hidden
end
structure Hide :> HIDE = struct
  type 'a hidden = 'a ref
  val make = ref
  val thing = make NONE
end
```


The *Value Restriction*

```
val thing = ref NONE (* : ?.X1 option ref *)
val _ = thing := SOME "hi"
val i = 1 + case !thing of NONE => 0 | SOME x => x
```

A variable-binding can have a polymorphic type only if the expression is a variable or value.

- Function calls like `ref NONE` are neither

Otherwise

```
Warning: type vars not generalized because of
   value restriction are instantiated to dummy types
```

(Basically unusable)

Not obvious: suffices to make type system sound.

Value Restriction downside

Causes problems when unnecessary (no mutation) because:

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

Type-checker does not know `List.map` is not making a mutable ref.

Workarounds for partial application:

wrap in a function binding to keep it polymorphic

```
fun pairWithOne xs = List.map (fn x => (x,1)) xs
(* 'a list -> ('a*int) list *)
```

give up on polymorphism; write explicit non-polymorphic type

```
val pairWithOne : int list -> (int * int) list =
   List.map (fn x => (x,1))
val pairWithOne = List.map (fn (x : int) => (x,1))
```

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 (later)

– Suppose pairs are supertypes of wider tuples
– Then `val (y,z) = x` constrains `x` to have at least two fields, not exactly two fields.
– Sometimes languages can support this, but types are often more difficult to infer and understand.