Type systems

We have seen types in the course already

- types as a description of a *data structure*
  - to generate code to allocate and construct variables
  - every identifier comes with a type

    variable declarations `char c`
- *type checking* (C, Pascal, ...)
  - detecting runtime errors: bad usage of variables
  - checking function calls `f(t1,..,tn)`
    - functions have types of the form $(\boldsymbol{\tau}^1 * \cdots * \boldsymbol{\tau}^n) \longrightarrow \boldsymbol{\tau}'$
    - the $\boldsymbol{\tau}_i, \boldsymbol{\tau}'$ must be provided by the programmer
  - some flexibility: subtyping `char` $\leq$ `int`
- types can also be used for *program analysis*
  - Hoare triples as types?

    $\{A\}\,p\,\{B\}$ can be written $p : A \rightarrow B$

    (assigning a type to a whole program)
- what *(inert)* data structures *are* vs what programs *do*

move to *richer types*

The language for types

- a lot of research in programming languages focuses on *type systems*
- analyse the behaviour of programs
  - absence of runtime errors
  - provide guarantees (termination, non-interference, complexity, protocol compliance, ..)
- two languages, for programs and for types
  - the notion of function is central
  - types for functions: $\tau_1 \to \tau_2$

programs FUN

types $\tau ::= \mathtt{int} \mid \tau_1 \to \tau_2$

Typing: definition

on the board

Exercise:

typing the CPS transform

Types in functional languages

- typing guarantees *absence of runtime errors*

  Theorem: if $\Gamma \vdash e : \tau$, then running e will not generate a bad application of a function to an argument.
- language design: functions, and function types, are *primitive* in functional languages
  - less constructs in the language of types, (no `struct`, `typedef`) but the language is somehow *richer*
  - promoting the use of functions: applications everywhere

    more typing, "hence" less bugs
- ML also has *polymorphic types*: `'a -> ('a -> 'b) -> 'b`
  - not only `:=` and `=` *(as seen before)*
  - the programmer can define polymorphic functions
  - `int -> (bool->int) -> bool` and `int -> (int->int) -> int` are instances of the type above
- types for functional programming languages have their origins in logic/proof theory
  - $\rightarrow$ stands for $\Rightarrow$
  - but $\forall$ *(as in `fun z -> z : 'a -> 'a`)* does not really stand for $\forall$

    $\forall$ is rather dependent types, as in Coq's type system

Type inference

Type inference as in ML / Haskell

- the core of ML/Haskell *(basically,* FUN*)*
  - not modules/functors
- no need for *any* annotation
  - input: a bare program
  - output: a type, or an error message
    the type, actually *(there are "principal types")*
- how does it work?
  1. constraint generation
  2. constraint solving

  Theorem: the generated constraint problem has a solution iff the program has a principal type.
- this approach, known as the Hindley-Milner approach, is *global*

Partial type inference

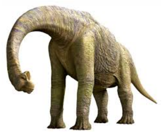
- issues in type inference
  - decidability
  - to a lesser extent, complexity
  - being intuitive / predictable
    readability of error messages
- some languages adopt *partial type inference*
  - pragmatical reasons
    - writing type annotations can be a good habit
    - but we don't want to write annotations which are
      . silly *nothing informative*
      . common *ok for rare situations*
  - theoretical reasons

    the type system is so rich (objects, subtyping, modules, polymorphism, ..) that we cannot decide inference
    Scala, ML, Coq
- an example: type inference in Scala
  - builds on Java: Java users praise type inference
  - is close to a functional language:
    functional programmers blame partiality

Bidirectional type inference

on the board

Programming languages zoology



Things left to say

- exam
  - all of the course (C+AP)
  - written documents (notes, books) are allowed
- évaluation