# Types-1

- What is a type?
- "Type safe" programs
- Strong type systems
- Type checking
  - Static versus dynamic
- Polymorphism
  - Ad hoc: coercion, overloading
  - Parametric: generics

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# What is a type?

- *Type*: a set of values and meaningful operations on them
- Types provide semantic *sanity checks* on programs
  - Analogous to units conversions in physics, convert feet per second to inches per minute
    - (feet/second) (seconds/minute) (inches/feet)
  - How specify types?
  - How check their usage in actual programs?

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## Types

- Implicit
  - If variables are typed by usage
    - Prolog, Scheme, Lisp, Smalltalk
- Explicit
  - If declarations bind types to variables at compile time
    - Pascal, Algol68, C, C++, Java
- Mixture
  - Implicit by default but allows explicit declarations
    - Haskell, ML

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## Type System

- Rules for constructing types
- Rules for determining/inferring the type of expressions
- Rules for type compatibility:
  - In what contexts can values of a type be used (e.g., in assignment, as arguments of functions,...)
- Rules for type equivalence or type conversion
  - Determining (ensuring) that an expression can be used in some context

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## Types of Expressions

- If *f* has type $S \rightarrow T$ and *x* has type *S*, then *f(x)* has type *T*
  - type of `3 div 2` is *int*
  - type of `round(3.5)` is *int*
- *Type error* - using wrongly typed operands in an operation
  - `round("Nancy")`
  - `3.5 div 2`
  - `"abc"+ 3`

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## Type Checking

- *Goal:* to find out as early as possible, if each procedure and operator is supplied with the correct type of arguments
  - Type error: when a type is used improperly in a context
  - Type checking performed to prevent type errors
- Modern PLs often designed to do type checking (as much as possible) during compilation

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## When type checking occurs?

- *Compile-time* (static)
  - At compile time, uses declaration information or can infer types from variable uses
- *Run-time* (dynamic)
  - During execution, checks type of object before doing operations on it
    - Uses type tags to record types of variables
- Combined (compile- and run-time) type checking
  - Most modern PLs

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## Type Safety

- A *type safe* program executes on all inputs without type errors
  - Goal of type checking is to ensure type safety
  - Type safe does not mean without errors

```
read n;
if n>0 then {y:="ab";
             if n<0 then x := y-5;}
```

  - Note that assignment to x is never executed so program is *type safe* (yet contains an error).

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## Strong Typing

- *Strongly typed PL*
  - PL requires all programs to be type checkable
  - PL's type system only accepts only safe expressions (guaranteed to evaluate without a type error)
- *Statically strongly typed PL* - compiler allows only programs that can be type checked fully at compile time
  - If the type of any expression can be fully determined at compile-time. How?
    - Explicit declaration, or
    - Type reconstruction (sometimes called type inference)

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## Strong Typing

- *Dynamically strongly typed PL* -Operations include code to check run-time types of operands, if type cannot be determined at compile time
  - C++, Java

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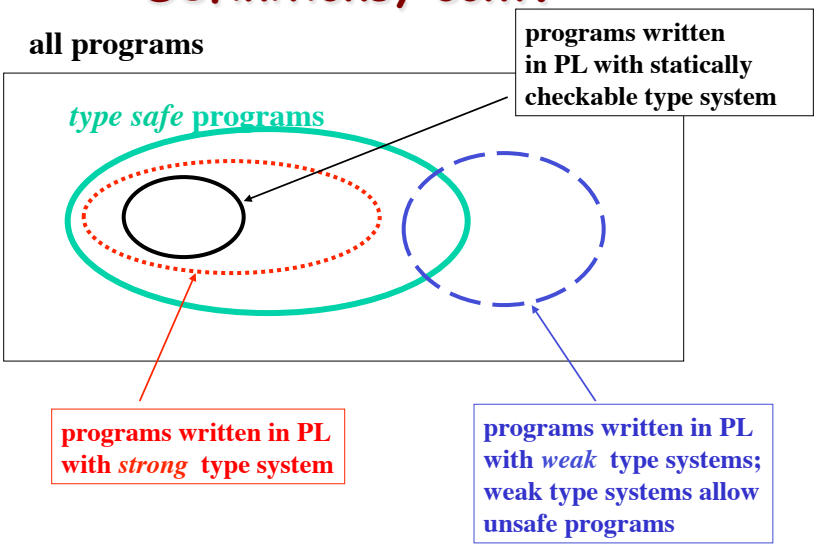
# Definitions, cont.

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# Type Equivalence

- Governs which constructed types are considered "equivalent" for operations such as assignment and copy statements
- Two main flavors:
  - Structural equivalence
  - Name equivalence

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## Types formed by construction

- Constructive point of view
  - Primitive types e.g., *int, char, bool, enum{*red,green,yellow*}*
  - Composite/constructed types:
    - reference e.g., *pointerTo(int)*
    - array e.g., *arrayOf(char)* or *arrayOf(char,20)* or ...
    - record/structure e.g., *record(*age*:int,* name*:string)*
    - union e.g. *union(int, pointerTo(char))*
    - list e.g., *list*(...)
    - function e.g., *float* → *int*

    CAN BE NESTED! pointerTo(arrayOf(pointerTo(char)))

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## Equality of Structured Types

- *Structural equivalence*: types are equivalent as terms
  - Same primitive type
  - Formed by application of same type constructors to structurally equivalent types
  - Shortcoming as shown in Pascal:

    type salary: int; var s: salary;

    type height: int; var y: height

    *cannot outlaw s+y by structural equivalence rules.*
  - Used by Algol-68, Modula-3, ML and C (except for its structs)

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## Equality of Structured Types

- *Name equivalence:* use name of type to assert equivalence
  - In Ada: type height: int

    var x: list (int) *x,y considered same type*
    var y: list (int) *y,s considered different types!*
    var s: list (height)
  - Shortcoming, in Pascal

    type cell = record info: int, next: ^cell end;
    type link = ^ cell;
    var first, last: link;
    begin if first.next = last then… *comparison isn't valid by either name or struct. eq*

    **types: ^cell link**

    **Used by Java**

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## Equality of Structured Types

- *Declaration equivalence:* variables need to be declared in same declaration statement.

  p: ^cell *p,q not compatible types*
  q: ^cell *s,t are compatible types*
  s,t: ^cell
- Bizarre rule not longer used (ISO Pascal)

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## Types

- *Monomorphic:* Conventionally, PL objects have one type
- *Polymorphic:* Some PLs allow objects to have more than one type (e.g., *nil* value for lists and pointers)

(good article on typing by Cardelli+Wegner Computer Surveys, 12/85)

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## Polymorphism

- *Ad hoc (apparent)* : function appears to work on several different types, but may behave in different ways for different types
  - *Overloading:* same name denotes different functions; compiler decides which one by context
  - *Coercion:* semantic operation needed to convert an argument to the correct type expected by the function
    - Statically or dynamically
    - Algol68 only allowed explicit type conversions, but it never caught hold so this solution is not popular

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## Polymorphism

- *Parametric:* function works uniformly on a range of types; (e.g., *cons, length*); often executes the same code no matter what type the arguments are
  - *Generic functions*: parameterized template which has to be instantiated to actual parameter values before usage
    - Macro-expansion semantics at compile-time
  - True parametric polymorphic functions have only 1 copy of code
    - ML is the paradigm PL

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## Polymorphism

- Ada, Pascal are monomorphic, but have
  - overloaded arithmetic operators, + * can have mixes of *real* or *int* arguments
  - coercion, *int* → *real* allowed
  - subtyping, 1..N is subtype of *int*
  - value sharing, *nil* shared by all pointer types

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# Typing Statements

- Problem: what to do about typing statements? use special type called *void*

| $\vdash y: \tau$ , $\vdash e: \tau$ | $\vdash s1$: void, $s2$:void | $\vdash b$:bool, $\vdash s$:void |
|---|---|---|
| $\vdash y := e$ : void | $\vdash s1; s2$ :void | $\vdash$ if b then s:void |
| *Assignment* | *Stmt sequence* | *If stmt* |

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