Types

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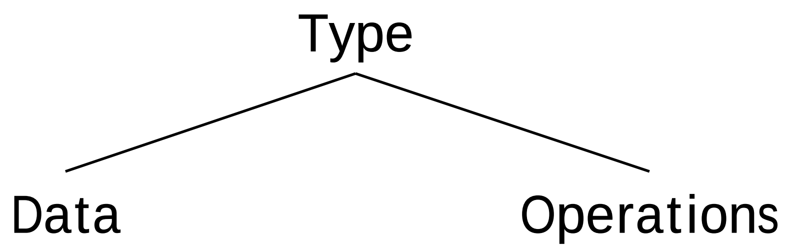
Topics

- Definition of a type
- Kinds of types
- Issues on types
- Type checking
- Type conversion

Components of a data type



- a set of data objects that model a collection of abstract objects in real world

  ex: in C language

  - **`int`** ↔ integers, student id, exam scores, …
  - **`char[]`** ↔ letters, names, …

- a set of operations that can be applied to the objects

  ex: **`+ - * /`** ↔ add, subtract, multiply, divide for integers

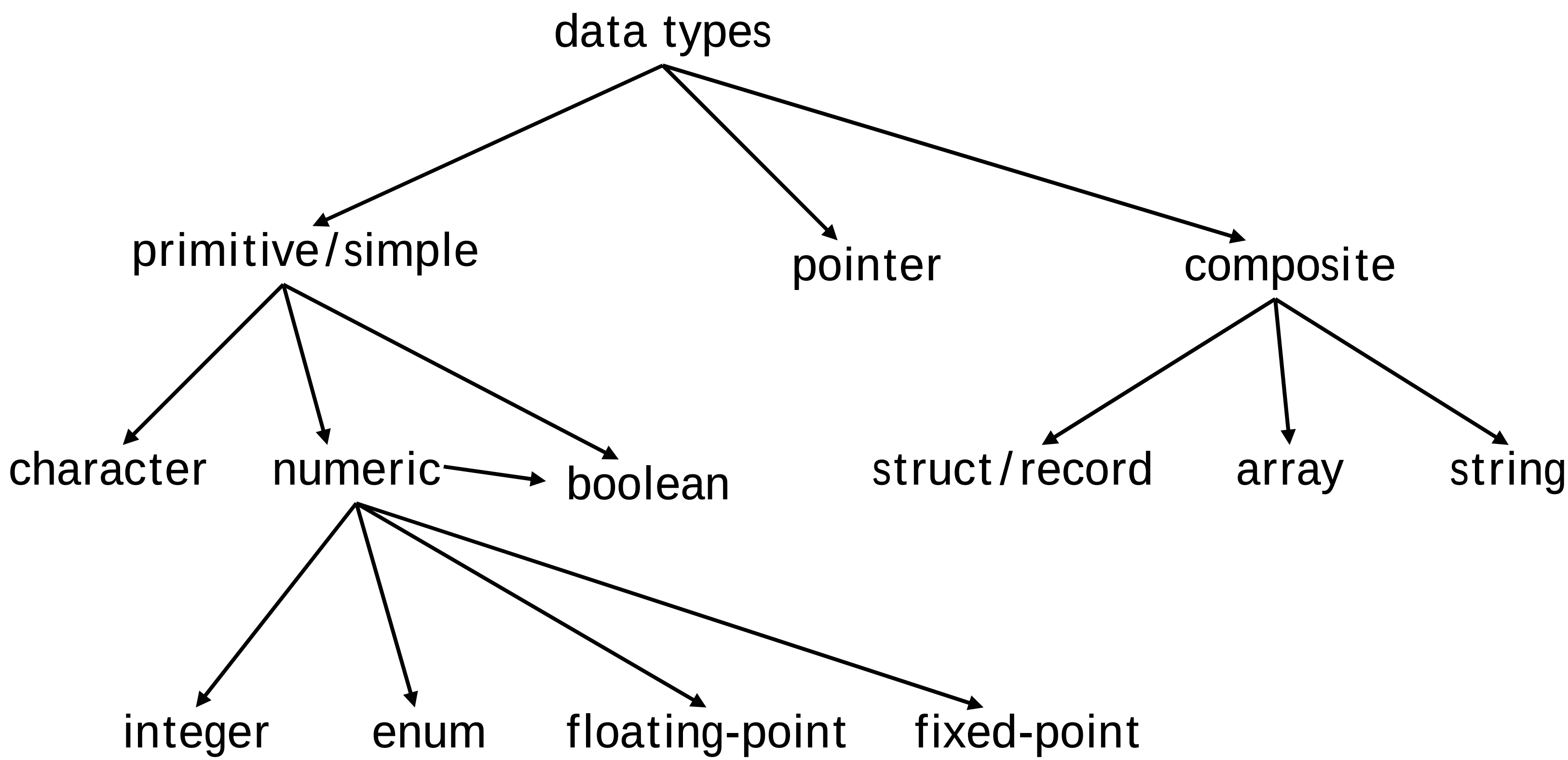
Using types …

- improves readability and writability.
  - ex:
    ```
    char* student_name;
    struct employee_records {
        char* name;
        int salary;
        . . .
    }
    ```
- reduces programming errors.
  - ex:
    ```
    student_name / 5
    ```
- makes memory allocation and data access efficient.
  - ex:
    ```
    struct {
        int i;
        char* c;
    }
    ```
    // 8 bytes → Sizes are statically known.

    → useful for the compiler to optimize memory allocation (e.g., use stack in stead of heap)

Hierarchies of types

- Most imperative languages (C/C++, Ada, ...)



C/C++ → char, int/long, float/double, struct/class, array, string(?)
Java → ... boolean

no clear distinction between char and int, no special op for char/string

Selection of data types

- "What kinds of types should be included in a language" is very important for programming language design.
- Primitive/simple types are supported in almost all existing programming languages
- Composite types being supported differ from language to language based on what is the purpose of the language.
- Several issues related to the selection of types
  - fixed-point vs. floating-point real numbers
  - array bounds
  - structure of composite types
  - pointer types
  - subtypes

Cobol for string type ?
class type for OO languages

Fixed-point vs. Floating-point

- fixed-point
  - Precision and scale are fixed.
    → a fixed radix point for all real numbers of the same type
  - ex: salary amount of graduate assistants
    → 6 digits for precision and 2 digits for scale
      → 1234.56, 2000.00
- floating-point
  - radix points are floating
  - ex: 21.32, 9213.1, 4.203e+9
- COBOL, PL/1 and Ada support the fixed-point real type, but most of other languages (Fortran, C, ...) don't.
  - Ada: `type salary is delta 0.01 range 0.0..3000.0`
  - C++: `float salary;`

Fixed-point vs. Floating-point

- Problem with fixed-point
  - possible loss of information after some operations at run-time
    - ex: *double the salary of EE students!*
- Problem with floating-point
  - Large numbers may be machine-dependent.
    - ex: *port a C-program to 32-bit and 64-bit machines!*
  - Less secure
    - ex: *double the salary illegally*

Determination of array bounds

- static arrays (C, Fortran, Pascal)
  - array bounds determined at compile time and static storage allocation. → efficient
  - ex: `int a[10], b[5];`
- dynamic (C, Fortran90)
  - array bounds determined at run time and dynamic storage allocation
  - ex:

```
int *a, *b;
a = b = new int[10]
         . . .
delete [] a;
b = new int[20]
```

Structure of composite types

```
struct man { char* name; int age; }
struct woman { char* name; int age; }
man Tom;
woman Jane;
   . . .
Jane = Tom;
```

- Is this assignment legal?
- In Ada and the early Pascal, the answer is "no".
  → *name equivalence/compatibility*
- In most others like C, the answer is "yes".
  → *structure equivalence*
- The name equivalence provides
  - easy type checking by string comparison → fast compilation
  - more secure and less error-prone compilation → `Jane = Tom;` *(unsafe!)*
  - less flexible programming
    - No <u>anonymous type</u> is allowed. → cf: C/C++
    - Type must be globally defined. → Why?

```
struct {
    char* name;
    int age;
} Tom;
```

The pointer type

- In C, the pointer type is a part of data types

```
int* p;
int i;
char c, d;
    . . .
p = &i;
d = *p;
```

→ *Error can be detected by the compiler*

  - *Most languages include the pointer type.*

Subtypes

- Primitive types provided by languages are not enough. Why?

```
int day, month;
month = 9;      // It's OK…but need more…
day = -11;      // Non-sense! Semantic error! may not be caught even at run time
```

  – *How can we capture this semantic error with data types?*

- Users need to restrict the primitive types.
  – enumerated types (C++, Pascal)
    - *C++*

```
enum day_type {first, second, . . . , thirty_first};
enum month_type {Jan, Feb, . . . , Dec};
day_type day;
month_type month;
month = Sep;          // That's better. More readable.
day = -11;            // Error detected at compile time!
```

Monomorphic/polymorphic objects

- A *monomorphic* object (function, variable, constant, ...) has a single type.
  - constants of simple types (character/integer/real): ‘a’, 1, 2.34, ...
  - variables of simple types: **`int i;`** *(C)*, **`x :real;`** *(Pascal)*
  - various user-defined functions: **`int foo(char* c);`**
- A *polymorphic (generic)* object has more than one types.
  - **`0`**(*integer,virtual function, pointer*) in C
  - the basic operators **`*`**(*multiply, dereference*), ...
  - derived class objects in object-oriented languages

Type expressions

- A *type expression* describes how the representation for a monomorphic or polymorphic object is built.
- Examples of type expressions in real languages
  - simple types

```
int, boolean, char*, ^real, ...
```

  - composite types

```
array [...] of real
char <name>[...]
struct {...}
record <name> is ... end <name> end record;
```

  - functions

```
float <function name>(...) { ... }
```

- Type expressions are useful to formally represent monomorphic and polymorphic objects.

Type expressions

- The syntax of type expressions for monomorphic and polymorphic objects
  - *int*, *real*, *list* . . . denote basic types.
  - α, β, . . . denote *type variables.*
  - the type constructors →, X are used for functions
- *Ex:*

726 : *int*

"string" : *char**

foo : *char* → int*

+ : { *real x real → real*, *int x int → int* }

***** : { *real x real → real*, *int x int → int*, $\alpha * \rightarrow \alpha$ }

```
int foo(char* c) {
   float a;
   …
}
```

Type checking

- Recall → **data type** = set of **data objects** + set of **operators**

  Examples — *Type expressions*

  - $* : int \times int \rightarrow int$ // type definition of a *monomorphic function* — *a function having a single, fixed type*
  - $\Sigma : list\ \alpha \rightarrow \alpha$ // type definition of a *polymorphic function* Σ — *a function having multiple types*

- A *data object* is **compatible** with an operator if the objects can be passed to the operator as the operands.

```
int i, j;
i * 3                 // legal
i * "string"          // illegal
Σ(1.3, 3.01, 2.0)     // legal
Σ(3.2, j, i)          // illegal
```

  - **Type error** occurs if an operator is applied to *incompatible* objects.
  - A program is **type safe** if it results in no *type error* while being executed.
  - **Type checking** is the activity of ensuring that a program is *type safe.*

Static vs. dynamic type binding

- static type binding
  - A variable ...
    - is bound to a certain type by a declaration statement, and
    - should have only one type during its life time.

```
float x;        // x is of a real type
char* x;        // This is an error
```

  - most existing languages such as Fortran, PL/1, C/C++ and ML
- dynamic type binding
  - A variable ...
    - is bound to a type when it is assigned a value during program execution, and
    - can be bound to as many types as possible.

```
> (define x 4.5)          // x is of a real type
> (define x '(a b c))     // now, x is of a list type
```

  - Scheme, LISP, APL, SNOBOL

Static type checking

- type checking performed during compile time
  - Pascal, Fortran, C/C++, Ada, ML, ...
  - The type of an expression is determined by static program analysis.
- To support static type checking in a language, a variable (or memory location) and a procedure must hold only one type of values, and this type must be statically bound or inferred.
  - C++

```
#include <stream.h>
main() {
        int i = bar(); // error: undefined function bar
        . . .
```

Dynamic type checking

- type checking performed during program execution
- required by languages that
  - perform dynamic type binding, or
    - *Scheme*

```
> (define a 10)
> (car a)
error: wrong arg to primitive car: 10
```

  - check the value of a program variable at run time.
    - *Pascal*

```
subtype day_type is integer range 1..31;
var day : day_type;
 i : integer;
. . .
day := i;                    // Is 1 ≤ i≤ 31?
```

Static vs. dynamic type checking

- STC supports early detection of type errors at compile time.
  Thereby … → shortening program development cycle, and causing no run time overhead for type checking.
- STC guarantees a program itself is type safe.
- DTC only guarantees a particular execution of a program is type safe. Therefore, DTC must be repeated although the same program is executed.
- DTC needs extra space for special bits for each variable indicating the type of the variable at present.
- In general, STC allows greater efficiency in memory space and time.
- DTC handles the cases with unknown values that STC cannot handle.

Strongly vs. weakly typed languages

- strongly typed (Ada, ML, Miranda, Pascal) if all (or almost all w/ few exceptions like Pascal) programs are guaranteed to be type safe by either static or dynamic type checking.
- weakly typed or untyped (Fortran, C/C++, Scheme, LISP)
  - C++

```
float foo(char cc, float x) { cout << cc << x; }
main() {
   float y = foo(100.7,'c');
```

// it runs! ➔ output: **d 99**

char(100.7) → char(100) → 'd'
float('c') → 99

Overloading

- Often it is more convenient to use the same symbol to denote several values or operations of different types.
  - C++

```
int ::operator+(int, int) { . . . }
float ::operator+(float, float) { . . . }
```

→ This built-in symbol + is overload because it is used for the addition for integer and real types.

- In C++, the users can overload operators with the class construct.

```
class complex {
        . . .
        complex operator+(complex, complex);
}
```

Overloading

- Type checking tries to resolve ambiguities in an overloaded symbol from the context of its appearance.

```
day_type day;
day = 10;              // 10 is of type day
. . . 3 + 4            // integer addition
. . . 4.3 + 2.1        // real addition
```

→ If the ambiguity cannot be resolved, type error occurs.

Type conversion

- In order to allow **`3.46 + 2`** instead of **`3.46 + 2.0`**, one solution is to create extra two overloaded functions

```
float ::operator+(float, int) {  . . . }
float ::operator+(int, float) {  . . . }
```

→ But, this solution is tedious and may cause exponential explosion of the overloaded functions for each possible combination of types such as **`short`**, **`int`**, **`long`**, **`float`**, **`double`**, **`unsigned`**, … .

- A better solution: type conversion

→ *convert the types of operands*.

- Two alternatives for type conversion
  - **explicit**: type cast
  - **implicit**: coercion

Type cast

- Explicit type conversion
  - *C++*

```
float x = 3.46 + (float) 2;
int *ptr = (int *) 0xffffff;
x = x + (float) *ptr;
```

- Drawback of type cast
  - Heedless explicit conversion may invoke *information loss*. (e.g. truncation)
  - A solution? → implicit type conversion!
    - Languages provide *implicit type conversion (coercion)* to coerce the type of some of the arguments in a direction that has preferably no information loss.

Coercion

- In many languages (PL/1, COBOL, Algol68, C), coercions are the rule. They provide a predefined set of implicit coercion precedences. → *Generally, a type is widened when it is coerced.*
  - *C*

```
character → int
pointer → int
int → float
float → double
   . . .
```

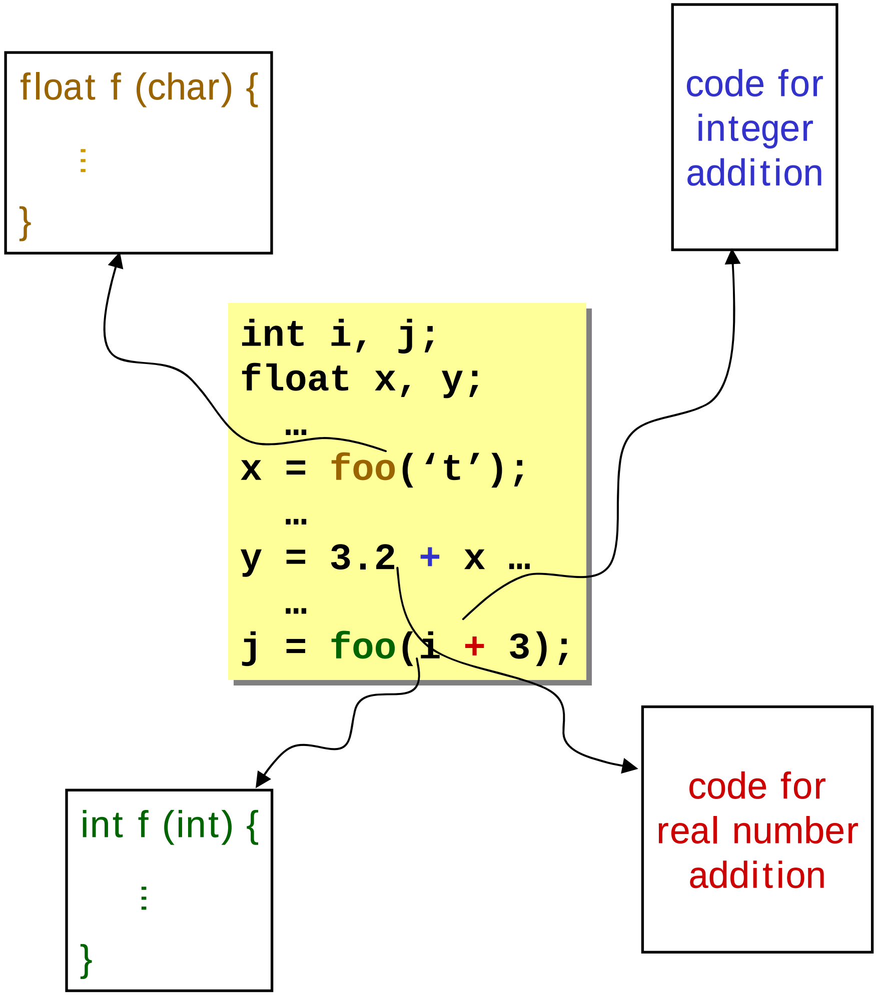
But, it may still lose information.
ex: 32 bit integer → 32 bit float with 24 bit mantisa)

Polymorphic functions

1. **ad-hoc** polymorphic functions that work on a finite number of types
   - *overloaded* functions
     - built-in → +, *, …
     - user-defined

       ```
       int foo(int i);
       float foo(char c);
       ```
   - functions with parameter *coercion*

     Ex: convert `real + int` to `real + real`
   - After the ambiguity is resolved, a *different piece of code* is used.



Polymorphic functions

2. **universal** polymorphic functions that work on an unlimited numbers of types
   - **inclusion** polymorphism is the type of polymorphism you're used to, where the same function can exist with the same signature in several child classes and act differently for each class
     → *subtypes*
   - **parametric** polymorphism is when a function accepts a variable as a parameter that can be of any valid type (e.g. variables in Scheme)
     → * (*dereference*)
     → Typically, the *same code* is used regardless of the types of the parameters, and the functions exploit a *common structure* among different types.