22c:111 Programming Language Concepts

Fall 2008

Types I

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5.1 Type Errors
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5.10 Programmer-Defined Types
**Def:** A *type* is a collection of values and operations on those values.

**Examples:**

- The Integer type has values ..., -2, -1, 0, 1, 2, ... and operations +, -, *, /, <, ...

- The Boolean type has values true and false and operations \(\land\), \(\lor\), \(\neg\).
Computer types have a finite number of values due to fixed size allocation; problematic for numeric types.

Exceptions:
- Smalltalk uses unbounded fractions.
- Haskell type `Integer` represents unbounded integers.

Floating point problems?
Even more problematic is fixed sized floating point numbers:

- 0.2 is not exact in binary.
- So 0.2 * 5 is not exactly 1.0
- Floating point is inconsistent with real numbers in mathematics.
In the early languages, Fortran, Algol, Cobol, all of the types were built in.

If needed a type color, could use integers; but what does it mean to multiply two colors.

Purpose of types in programming languages is to provide ways of effectively modeling a problem solution.
5.1 Type Errors

Machine data carries no type information.
Basically, just a sequence of bits.
Example: 0100 0000 0101 1000 0000 0000 0000 0000
• The floating point number 3.375
• The 32-bit integer 1,079,508,992
• Two 16-bit integers 16472 and 0
• Four ASCII characters: @ X NUL NUL
**Def:** A *type error* is any error that arises because an operation is attempted on a data type for which it is undefined.

Type errors are common in assembly language programming.

High level languages reduce the number of type errors.
Def: A *type system* is a precise definition of the bindings between the types of a variable, its values, and the possible operations over those values. A type system provides a basis for detecting type errors.
5.2 Static and Dynamic Typing

A type system imposes constraints (such as the values used in an addition must be numeric).

• Cannot be expressed syntactically in EBNF.

• Some languages perform type checking at compile time (eg, C, C++, OCaml).

• Other languages (eg, Perl, Scheme, Python) perform type checking at run time.

• Still others (eg, Java) do both.
Def: A language is *statically typed* if the types of all variables are fixed when they are declared at compile time.

Def: A language is *dynamically typed* if the type of a variable can vary at run time depending on the value assigned.

Can you give more examples of each?
Def: A language is *strongly typed* if its type system allows all type errors in a program to be detected either at compile time or at run time.

Note: A strongly typed language can be either statically or dynamically typed.

*Union* types are a hole in the type system of many languages (eg, C, C++).

Most dynamically typed languages associate a type with each value.
5.3 Basic Types

Terminology in use with current 32-bit computers:

- Nibble: 4 bits
- Byte: 8 bits
- Half-word: 16 bits
- Word: 32 bits
- Double word: 64 bits
- Quad word: 128 bits
In most languages, the numeric types are finite in size. So $a + b$ may overflow the finite range.

Unlike mathematics:

$$a + (b + c) \neq (a + b) + c$$

Can you see why?
Also in C-like languages, the equality and relational operators produce an int, not a Boolean

- \( (2 < 4) \) evaluates to 0
- \( (2 > 4) \) evaluates to 1
- if 5 {...} else {...} is legal, and meaningful, code!
Def: An operator or function is overloaded when its meaning varies depending on the types of its operands or arguments or result.

Java: $a+b$ (ignoring size)
- integer add
- floating point add
- string concatenation

Mixed mode: one operand an int, the other floating point
Languages that allow mix mode syntax introduce implicit type conversion between values (eg. 3.4 + 1 is treated as 3.4 + intToFloat(1))

**Def:** A type conversion is a *narrowing* conversion if the result type permits fewer bits, thus potentially losing information. Otherwise it is a *widening* conversion.

Should languages ban *implicit* narrowing conversions? Why?
5.4 Nonbasic Types

Enumerations

enum day {Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday};
enum day myDay = Wednesday;

In C/C++ these just define an int range [0..6] where Monday == 0, Tuesday == 1 and so on
Enumeration types are powerful in Java:

for (day d : day.values()) System.out.println(d);

They are even more powerful in Ocaml, Haskell as they a special case of *algebraic data types* (more on them later)
Pointers

C, C++, Ada, Pascal
Java?? OCaml??

The values in a pointer type are memory addresses

They are used for indirect referencing of data

Operator in C: *
Example

```c
struct Node {
    int key;
    struct Node* next;
};
struct Node* head;
```
Fig 5.4: A Simple Linked List in C
Pointers

Bane of reliable software development

Error-prone

Buffer overflow, memory leaks

Particularly troublesome in C
void strcpy(char *p, char *q) {
    while (*p++ = *q++)
}
Pointer Operations

If $T$ is a type and $\text{ref } T$ is a pointer:

$\& : T \rightarrow \text{ref } T$

$* : \text{ref } T \rightarrow T$

For an arbitrary variable $x$:

$*(\& x) = x$
Arrays

int a[10];
float x[3][5]; /* odd syntax vs. math */
char s[40];
/* indices: 0 ... n-1 */
Array Indexing

Only operation for many languages

Type signature

\[ \text{[ ] : T[ ] x int} \rightarrow T \]

Example

float x[3][5];

\text{type of x: float[ ][]}

\text{type of x[1]: float[ ]}

\text{type of x[1][2]: float}
Equivalence between arrays and pointers in C/C++

\[ a = \&a[0] \]

If either \( e1 \) or \( e2 \) is type: ref T

\[ e1[e2] = *(e1 + e2) \]

Example: \( a \) is float[ ] and \( i \) int

\[ a[i] = *(a + i) \]
float sum(float a[], int n) {
    int i;
    float s = 0.0;
    for (i = 0; i<n; i++)
        s += a[i];
    return s;
}

float sum(float *a, int n) {
    int i;
    float s = 0.0;
    for (i = 0; i<n; i++)
        s += *a++;
    return s;
Strings

Now so fundamental, directly supported.

In C, a string is a 1D array with the string value terminated by a NULL character (value = 0).

In Java, Perl, Python, a string variable can hold an unbounded number of characters.

Libraries of string operations and functions.
Structures (aka Records)

Analogous to a tuple in mathematics
Collection of elements of different types
Used first in Cobol, PL/I
Absent from Fortran, Algol 60
Common to Pascal-like, C-like, ML-like languages,
Omitted from Java as redundant
struct employeeType {
    int id;
    char name[25];
    int age;
    float salary;
    char dept;
};

struct employeeType employee;
...

employee.age = 45;
Unions

C: union
Pascal: case-variant record
Logically: multiple views of same storage
Useful in some systems applications

In functional languages, superseded by recursive data types (sometimes also called union types or algebraic data types)
(* Union type in Pascal *)

```pascal

type union = record
  case b : boolean of
  true : (i : integer);
  false : (r : real);
end;

var  u : union, j: integer;

begin
  u := (b => false, r => 3.375);
  j := tagged.i;  (* will generate error *)
```

// simulated union type in Java

class Value extends Expression {

    // Value = int intValue | boolean boolValue
    Type t; int intValue; boolean boolValue;

    Value(int i) { intValue = i;
                   t = new Type(Type.INTEGER);
               }

    Value(boolean b) { boolValue = b;
                      t = new Type(Type.BOOLEAN);
               }
}