22c:111 Programming Language Concepts

Fall 2008

Types I

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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 ∧, ∨, ¬.

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

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()) Sytem.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

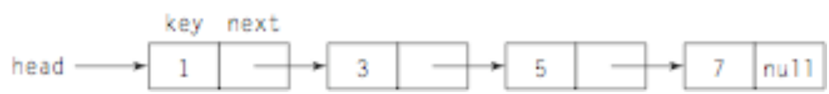
They are used for indirect referencing of data

Operator in C: *

Example

```
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

strcpy

```
void strcpy(char *p, char *q) {
   while (*p++ = *q++)  ;
}
```

Pointer Operations

If T is a type and 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

[ ] : T[ ] x int → T

Example

float x[3] [5];

type of x: float[ ][ ]

type of x[1]: float[ ]

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)

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

```c
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 *)
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);
    }
```