CSE 3302
Programming Languages

Data Types

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Algorithms+Data Structures=Programs

- Niklaus Wirth, 1976.

- Most languages clearly show traces of both
- Some languages appears to be mostly data?
- Some languages appears to be mostly control?

Data Types

- What is a data type?

  A name with certain attributes:
  - The values that can be stored, the internal representation, the operations, …
- A data type is a set of values
  - e.g., `int` in Java:

    `int x;`

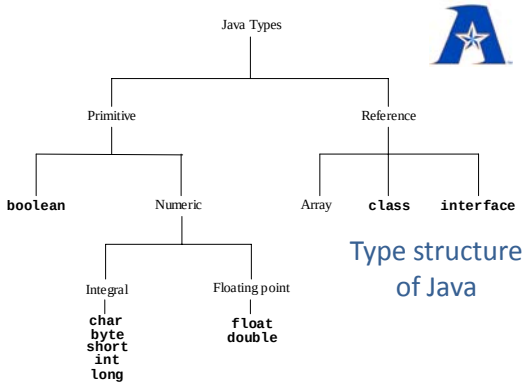
    x∈Integers= [-2147483648, 2147483647]
- A data type is also a set of operations on the values
- Thus a data type is an algebra

Why are data types important?

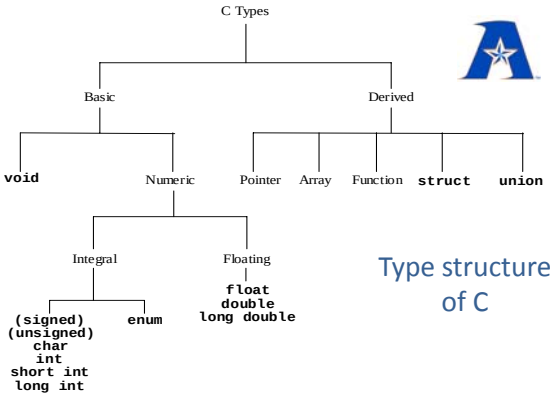
- Example: Z = x / y; (Java)
  - int x, y; x=5; y=2;
    - Integer division, x/y results in 2.
    - int z: z = 2;
    - double z: z=2.0;
  - double x, y; x=5; y=2;
    - floating-point division, x/y results in 2.5
    - int z: wrong!
    - double z: z=2.5;

Data Types in Sample Languages

- Different terminologies and hierarchies for similar things.



Type structure of Java



Type structure of C

Simple Data Types

- No internal structure:
  e.g., `integer`, `double`, `character`, and `Boolean`.
- Often directly supported in hardware.
  - machine dependency
  - standardization efforts: e.g., IEEE standard 754 floating point
    - Single precision: 32 bit representation with 1 bit sign, 8 bit exponent, 23 bit mantissa
- Most predefined types are simple types.
  - Exceptions: *String* in Java.
- Some simple types are not predefined
  - Enumerated types
  - Subrange types

Enumerated Types

ordered set, whose elements are ***named*** and ***listed*** explicitly.

- Examples:

```
enum Color_Type {Red, Green, Blue};        ( C )
type Color_Type is (Red, Green, Blue);     (Ada)
datatype Color_Type = Red | Green | Blue;  (ML)
```

- Operations: ?
  Successor and predecessor

Ada Example

```
type Color_Type is (Red, Green, Blue);

x : Color_Type := Green;
x : Color_Type'Succ(x);
x : Color_Type'Pred(x);
put(x);        -- prints GREEN
```

- No assumptions about the internal representation of values
- Print the value name itself

Pascal Example

```
type
     cardsuit = (club, diamond, heart, spade);
     card = record
               suit: cardsuit;
               value: 1 .. 13;
            end;
var
     hand: array [ 1 .. 13 ] of card;
```

- `Succ(diamond) = heart; Pred(spade) = heart;`
- `club < heart;` is true.
- `for acard := club to heart do`

C Example

```
#include <stdio.h>
enum Color {Red, Green, Blue};
enum Courses {CSE1111=1, CSE3302=3, CSE3310=3, CSE5555=4};
main() {
    enum Color x = Green;
    x++;
    printf("%d\n",x);
    printf("%d\n",Blue+1);
   return 0;
}
```

What's the result?

- `Enum` in C is simply `int`
- Can customize the values

Subrange Types

contiguous subsets of simple types, with a ***least*** and **greatest** element.

- Example:

```
type Digit_Type is range 0..9;          (Ada)
```

- Not available in C,C++,Java. Need to use something like:

```
byte digit;    //-128..127
...
if (digit>9 || digit <0) throw new DigitException();
```

- defined over **ordinal types:**
  - ordered, every value has a next/previous element
    - E.g., integer, enumerations, and subrange itself
  - Even floating number is ordinal type in Ada
    - `Unit_Interval is digits 8 range 0.0 .. 1.0;`

Evaluation of Enumeration Types

- **Efficiency** – e.g., compiler can select and use a compact efficient representation (e.g., small integers)
- **Readability** -- e.g. no need to code a color as a number
- **Maintainability** – e.g., adding a new color doesn't require updating hard-coded constants.
- **Reliability** -- e.g. compiler can check operations and ranges of value.

Courtesy of Charles Nicholas at UMBC

Type constructors: Defining New Types

- Remember our view of data types as sets?
- Type constructors as set operations:
  - Cartesian product
  - Union
  - Subset
  - Functions (Arrays)
- Some type constructors do not correspond to set operations (e.g., pointers)
- Some set operators don't have corresponding type constructors (e.g., intersection)

Cartesian Product

- **Ordered Pairs of elements from U and V**

  $U \times V = \{(u, v) \mid u \in U \text{ and } v \in V\}$

- **Operations:**
  - **projection**

    $p_1: U \times V \rightarrow U$; $p_2 : U \times V \rightarrow V$

    $p_1((u,v))=u$; $p_2((u,v))=v$
  - **copy**

Examples

- `struct` in C

```
struct IntCharReal
{    int i;
     char c;
     double r;
}
```

`int × char × double`

- `record` in Ada

```
type IntCharReal is record
     i: integer;
     c: character;
     r: float;
end record;
```


The same type?

```
struct IntCharReal
{    int i;
     char c;
     double r;
}

struct IntCharReal
{    char c;
     int i;
     double r;
}
```

The same type?

```
struct IntCharReal
{    int i;
     char c;
     double r;
}

struct IntCharReal
{    int j;
     char ch;
     double d;
}
```


Record/structure are not exactly Cartesian products

- Component selector: projection by component names

```
struct IntCharReal x;
x.i;
```

- Most languages consider component names to be part of the type.
- Thus the previous two types can be considered different, even though they represent the same Cartesian product.

ML: Pure Cartesian Product

```
type IntCharReal = int * char * real;
```

- `(2, #"a", 3.14): string * int`
- `#3(2, #"a", 3.14) = 3.14`

Union

- $U \cup V = \{x \mid x \in U \text{ or } x \in V\}$
  - data items with different types are stored in overlapping region, reduce memory allocation.
  - Only one type of value is valid at one time.
  - E.g.,

```
union IntOrReal {
      int i;
      double r;
}
```

- Different from records?

Undiscriminated Union in C

```
union IntOrReal {
        int i;
        double r;
}
union IntOrReal x;
x.i = 1;
printf("%f\n", x.r);
```

- Can be unsafe

Create Discriminated Union in C++

```
struct IntOrReal {
    bool isInt;
    union {
          int i;
          double r;
    };
};

IntOrReal x;
x.isInt = true;
x.i = 1;
...
if (x.isInt) printf("%d\n", x.i);
else printf("%f\n", x.r);
```

- Safe now
- or not?

Discriminated Union in Ada

- Variant record (with tag or discriminator)

```
type Disc is (IsInt, IsReal);
type IntOrReal (which: Disc) is
record
   case which is
        when IsInt =>  i: integer;
        when IsReal =>  r: float;
   end case;
end record;
...
x: IntOrReal := (IsReal, 2.3);
put (x.i);  -- generates ERROR
```

- Safe: programmers won't be able to create inconsistent data

Discriminated Union in Pascal

- Variant record
- Can be unsafe:
  - First, the tag is optional
  - Second, the tag can be set inconsistently.

Discriminated Union in ML

```
datatype IntOrReal =
     IsInt of int | IsReal of real;
```

- `val x = IsReal(2.3);`

How about Java?

- Is there record or union in java? Why?

"Union" in Java

- `public abstract class A {…};`
  `public class B extends A {…};`
  `public class C extends A {…};`

  Abstract class A: union of B and C.

- Discriminated union: `instanceof`