CSc 520 — Principles of Programming Languages

13 : Types — Introduction

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1 Why types?

- *Types save typing.*
- What does `a+b` mean?
- In Java it could be
  1. `a` $+_{\texttt{int}}$ `b`.
  2. `a` $+_{\texttt{float}}$ `b`.
  3. `a` $\texttt{concat}_{\texttt{string}}$ `b`.
  4. `int2float(a)` $+_{\texttt{float}}$ `b`.
  5. `a` $+_{\texttt{float}}$ `int2float(b)`.
  6. `int2string(a)` $\texttt{concat}_{\texttt{string}}$ `b`.

  etc, all depending on the types of `a` and `b`.

2 Why types. . . ?

- In Icon variables are not given explicit types. Instead, operations carry the types:
  1. `a|b` means binary or on integers.
  2. `a||b` means string concatenation.
  3. `a|||b` means list concatenation.

  Icon has **lots** of operators. . .
- In other words, without types, we would have to be much more explicit about which operations are performed where.

3 Why types...?

- Icon programs become a bit wordier since every operator effectively encode the required type of the operands.
- On the other hand, it also becomes more readable since we can see directly from the operator what operation will be performed.

```
global x,y,z
procedure p()
   x := x + y    # integer addition
   x := x || y   # string concatenation
   x := x ||| y  # list concatenation
end
```

4 Why types...?

- To figure out which operation is performed in a Java program, we have to find the declarations of all variables to find their declared type:

```
int x;
String y;
float z;
void p() {
   x = x + 5;      /* integer addition */
   z = z + 5.0;    /* float addition */
   y = y + "X";    /* string concatenation */
}
```

5 Why types...?

- *Types prevent errors.*
  - Types save the programmer from himself.
  - Types prevent us from adding a character and a record.

  ```
  int A[20];
  float x;
  void p() {
     A[5] = x;
     A[x] = 5;
     x = x + A;
  }
  ```

6 Why types...?

- *Types permit optimization.* A compiler can generate better code for `a+b` if it knows that both variables must be integers, than if the exact types aren't known until runtime:

```
global a,b
procedure p() {
   a = new array [20]
   ...
   b = new array [20]
   ...
   a = a + b   /* what operation is performed here? */
}
```

7 Type Systems

- A *type system* consists of
  - a mechanism for *defining types*,
  - rules for *type equivalence*,
  - rules for *type compatibility*,
  - rules for *type inference*.

8 Type Systems...

- *Type equivalence* determines when the types of two values are the same:

```
TYPE A = ARRAY [0..10] OF CHAR;
TYPE B = ARRAY [0..10] OF CHAR;
VAR a : A;
VAR b : B;
BEGIN
   a := b; (* legal? *)
END
```

- Are the types of `a` and `b` the same?

9 Type Systems...

- *Type compatibility* determines when a value of a given type can be used in a given context:

```
VAR a : float;
VAR b : int;
BEGIN
   a := a + b;
END
```

- Can you add an `int` and a `float`?

10 Type Systems...

- *Type inference* defines the type of an expression based on its parts and surrounding context:

```
global a,b,c
procedure p(x)
   if x = 5 then
      a := x
   else
      a := "hello"
   write(a)
end
procedure main()
   p(5)
end
```

- What type of data can be written here?

11 Type Checking

- *Type checking* ensures that a program obeys a language's type rules.
- A *type clash* is a violation of the typing rules.

```
class C {
   void p() {
      int x = new C();
   }
}
```

12 Type Checking — Strong Typing

- Language L is *strongly typed* if
  - $\oplus$ is an operator in L that expects an object of type T,
  - L prohibits $\oplus$ from accepting objects of any other type,
  - and L requires an implementation (a compiler, interpreter, etc) to enforce this prohibition.
- In other words, a strongly typed language does not allow us to perform operations on the "wrong" type of data.

13 Type Checking — Weak Typing

- In a *weakly typed* language there are ways to "escape" the type system.
- In C, for example, it is possible to cast a pointer to a `float`, add 3.14 to it, and cast it back to a pointer:

```
int main() {
   int* p = (int*) malloc (sizeof(int));
   float f = *((float*) &p) + 3.14;
   p = (int*)(*(int *)&f);
}
```

- Such operations are probably meaningless and a strongly typed language would prohibit them.

14 Type Checking — Static/Dynamic Typing

- A language *statically typed* if type checking is done at compile-time.
- A language *dynamically typed* if type checking is done at run-time.
- In practice, even languages which are considered statically typed do some checking at run-time.
- Languages can usually be classified as *mostly strongly typed*, *mostly statically typed*, etc.

15 Terminology

- Benjamin C. Pierce has said:

  > I spent a few weeks ... trying to sort out the terminology of *strongly typed, statically typed, safe,* etc., and found it amazingly difficult. ... The usage of these terms is so various as to render them almost useless.

- It is possible to say

  > My language is more strongly typed than your language.

  but harder to argue that

  > My language is strongly typed/statically typed, etc.

16 Examples — Pascal

- Pascal is mostly strongly and statically typed.
- *Untagged variant records* are a loophole. They allow us to turn a value of one type into an object of some unrelated type.
- Unlike C, array bounds are checked.

17 Pascal – Untagged Variant Records

```
type rec = record
              a : integer;
              case boolean of
                 true : (x : integer);
                 false : (y : char);
           end;

var r: rec;
begin
   r.x := 55; r.y := 'A'; write(r.x);
end.
```

- This construct is used to bypass Pascal's strong typing.

18 Examples — C

- C is weakly and statically typed.
- Pointers can be cast willy-nilly which makes it easy to bypass the type system.
- Array references are not checked:

  ```
  int main() {
     int A[20];
     int B[20];
     A[25] = 5;
  }
  ```

  Negative indices were used in the old days to overwrite the operating systems.
- Today, buffer overflows are how most viruses compromise security.

19 Examples — Ada

- Ada is strongly and mostly statically typed.
- Unlike Pascal, variant records must be tagged:

```
type Device is (Printer, Disk, Drum);
type Peripheral(Unit : Device := Disk) is record
    case Unit is
       when Printer => Line_Count : Integer ;
       when others =>  Cylinder   : CIndex;
    end case;
    end record;
```

20 Examples — Ada...

- It is, however, possible to do *non-converting casts* (similar to C), but in a very explicit way:

  ```
  function float2int is
      new unchecked_conversion(float,integer);
  ...
  f := float2int(i);
  ```
- Some errors can't be checked at compile-time:

  ```
  I, J : Integer range 1 .. 10 := 5;
  K    : Integer range 1 .. 20 := 15;
  I := J;  --  identical ranges
  K := J;  --  compatible ranges
  J := K;  --  will raise an exception if K>10
  ```

21 Examples — Scheme

- Scheme is completely dynamically typed, so programmers often insert extra checks:

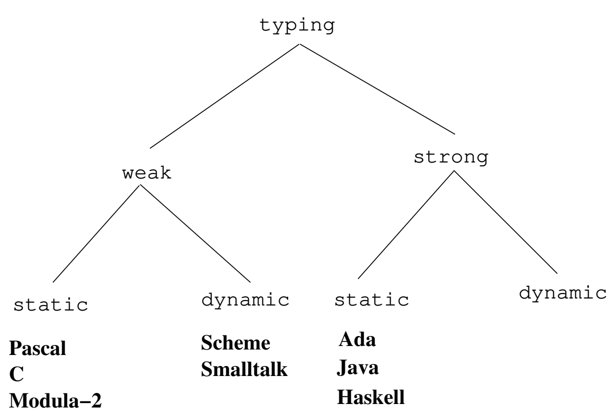
```
(define (sum l)
   (cond
      ((null? l) 0)
      ((not (list? l))
             (error "list expected"))
      ((not (number? (car l)))
             (error "list of numbers expected"))
      (else (+ (car l) (sum (cdr l))))
))
```

22 Examples — Java

- Java is strongly and mostly statically typed.
- An exception is thrown here because an `A`-object can't be cast to a `B`-object:

```
class A {}
class B extends A {
   int x;
}
void p() {
   B b = (B) new A();
}
```

23 Typing



24 Type Inference

- In statically typed languages types are inferred in the compiler, before the program is run:

```
procedure p (x : integer);
var z : real;
var c : char;
```

```
begin
   write(x + z);  /* convert x to real,
                     write a real */
   write(c + z);  /* type error */
end
```

25 Type Inference...

- Haskell and similar languages don't require the programmer to give types to variables and functions.
- Instead, the compiler infers types.
- Given

  ```
  len [] = 0
  len _:xs = 1 + len xs
  ```

  the Haskell translator will infer a *most general type*:

  ```
  len :: [a] -> Int
  ```

- Haskell is strongly and statically typed, although the programmer rarely have to provide explicit type information.

26 So, What is a Type?

- There are three ways to think about types:
  1. *denotational view* — a type is a set of values;
  2. *constructive view* — a type is what we can construct from the type constructors in the language;
  3. *abstraction-based view* — a type denotes a data object and a well-defined set of allowable operators on this object.
- At different times, we may look at a type in any of these ways.

27 Denotational View

- A type T is a set of values $\{t_0, t_1, t_2 \ldots\}$.
- A value v is of type T if it belongs to the set.
- A variable v is of type T if it is guaranteed to always hold a value in the set.
- A `char` type in Pascal is the set of 128 seven-bit ASCII characters:

  ```
  {...,
   "0",...,"9",...,
   "A",...,"Z",...,
   "a"...,"z",...}
  ```

28 Constructive View

- A Pascal type is (roughly)

  type ::=
  <u>integer</u> | <u>real</u> | <u>char</u> | <u>boolean</u> ...
  <u>[</u> expr <u>..</u> expr <u>]</u> |
  <u>SET OF</u> type |
  <u>ARRAY</u> type <u>OF</u> type |
  <u>RECORD</u> [field_list] <u>END</u>

- I.e., a Pascal type is either one of the built-in types, or ones we define ourselves by composing *type constructors*, such as `ARRAY`, `RECORD`, etc:

```
END T = RECORD
    a : real;
    b : ARRAY ["a".."z"] OF SET OF char;
END;
```

29 Abstraction-Based View

- A type is an *abstract data type*.
- The next slides shows what the Modula-3 language manual says about the operations that are allowed on `Words`.
- The allowed operations include arithmetic and logical operations.
- There is no "pointer dereferencing" operation defined, however, so apparently this operation is not allowed.

30 Abstraction-Based View...

```
INTERFACE Word;
   TYPE T = INTEGER;
   PROCEDURE Plus  (x,y: T): T;
   PROCEDURE Times (x,y: T): T;
   PROCEDURE Minus (x,y: T): T;
   PROCEDURE Divide(x,y: T): T;
   PROCEDURE Mod(x,y: T): T;
   PROCEDURE LT(x,y: T): BOOLEAN;
   PROCEDURE LE(x,y: T): BOOLEAN;
   PROCEDURE GT(x,y: T): BOOLEAN;
   PROCEDURE GE(x,y: T): BOOLEAN;
   PROCEDURE And(x,y: T): T;
   PROCEDURE Or (x,y: T): T;
   PROCEDURE Xor(x,y: T): T;
   PROCEDURE Not  (x: T):  T;
   PROCEDURE Shift(x: T; n: INTEGER): T;
   PROCEDURE Rotate(x: T; n: INTEGER): T;
   PROCEDURE Extract(x: T; i, n: CARDINAL): T;
   PROCEDURE Insert(x: T; y: T; i, n: CARDINAL): T;
END Word.
```

31 Readings and References

- **Read Scott, pp.307–312**.