CSc 520

Principles of Programming Languages

14 : Types — Classification

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Enumerable Types

- Also called discrete types or ordinal types.
- Discrete types are countable, or 1-to-1 with the integers.
- Examples:

1. integer
2. boolean
3. char
4. subranges
5. enumeration types

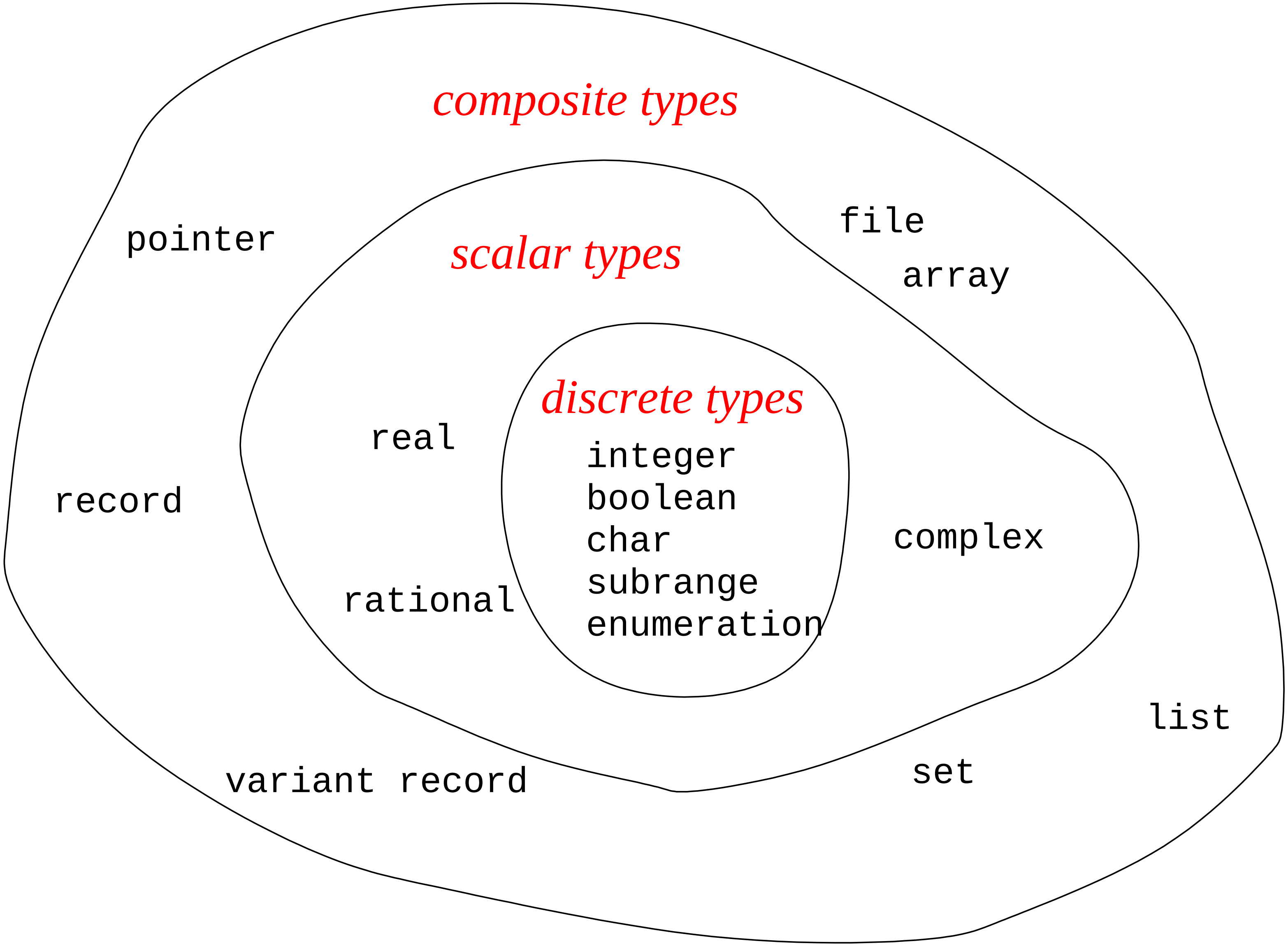
Scalar Types

- Also called simple types.
- The scalar types include:
  1. discrete types
  2. real
  3. rational
  4. complex

Composite Types

- Also called constructed types.
- They are created by applying type constructors to other, simpler, types.
- The composit types include:
  1. records
  2. variant records
  3. arrays
  4. sets
  5. pointers
  6. lists
  7. files

Types — Overview



Discreet Types — Enumerations

- Pascal, Ada, Modula-2, C have some variant of enumeration types.
- C's enumerations are just syntactic sugar for integer constants.
- In Pascal and Ada, enumerations are real types, incompatible with other types.
- In Ada and C, enumeration values can be user specified.

```
TYPE Color = (white,blue,yellow,green,red);
TYPE Fruits = (apple=4,pear=9,kumquat=99);
VAR A : ARRAY Color OF Fruit;
FOR c := white TO red DO
   IF c != yellow THEN A[c] := apple;
```

Discreet Types — Subranges

- Subranges can be used to force additional runtime checks.
- Some languages use subrange types as array index types.

```
TYPE S1 = [0..10];
TYPE S2 = ['a'..'z'];
TYPE Color = (white,blue,yellow,green,red);
TYPE S3 = [blue..green];
TYPE A = ARRAY S3 OF INTEGER;
VAR X : S3 := white; (* ⇐ error *)
```

Structured Types

Arrays – Storage Layout

- Most languages lay out arrays in row-major order. FORTRAN uses column-major.

Matrix

A[1,1]	A[1,2]
A[2,1]	A[2,2]
A[3,1]	A[3,2]
A[4,1]	A[4,2]

Row Major

0	A[1,1]
1	A[1,2]
2	A[2,1]
3	A[2,2]
4	A[3,1]
5	A[3,2]
6	A[4,1]
7	A[4,2]

Column Major

0	A[1,1]
1	A[2,1]
2	A[3,1]
3	A[4,1]
4	A[1,2]
5	A[2,2]
6	A[3,2]
7	A[4,2]

Array Indexing – 1 Dimensions

- How do we compute the address (L-value) of the n:th element of a 1-dimensional array?
- $\mathtt{A_{elsz}}$ is A's element-size, $\mathtt{A_{addr}}$ is its base address.

```
VAR A : ARRAY [l ..  h] OF T;
```

$$
\begin{aligned}
\mathtt{L-VAL}(A[i]) &\equiv \mathtt{A_{addr}} + (i - l) * \mathtt{A_{elsz}} \\
&\equiv \mathtt{A_{addr}} + (l * \mathtt{A_{elsz}}) + i * \mathtt{A_{elsz}} \\
C &\equiv \mathtt{A_{addr}} + (l * \mathtt{A_{elsz}}) \\
\mathtt{L-VAL}(A[i]) &\equiv C + i * \mathtt{A_{elsz}}
\end{aligned}
$$

- Note that C can be computed at compile-time.

Array Indexing – 2 Dimensions

VAR A **:ARRAY** $[l_1..h_1][l_2..h_2]$ **OF** T;

$$
\begin{aligned}
w_1 &\equiv h_1 - l_1 + 1\\
w_2 &\equiv h_2 - l_2 + 1\\
\mathtt{L}-\mathtt{VAL}(A[i_1, i_2]) &\equiv \mathtt{A}_{\mathtt{addr}} + ((i_1 - l_1) * w_2 + i_2 + l_2) * \mathtt{A}_{\mathtt{elsz}}\\
&\equiv \mathtt{A}_{\mathtt{addr}} + (i_1 * w_2 + i_2) * \mathtt{A}_{\mathtt{elsz}} -\\
&\quad (l_1 * w_2 - l_2) * \mathtt{A}_{\mathtt{elsz}}\\
C &\equiv \mathtt{A}_{\mathtt{addr}} - (l_1 * w_2 - l_2) * \mathtt{A}_{\mathtt{elsz}}\\
\mathtt{L}-\mathtt{VAL}(A[i_1, i_2]) &\equiv (i_1 * w_2 + i_2) * \mathtt{A}_{\mathtt{elsz}} + C
\end{aligned}
$$

- C can be computed at compile-time.

Array Indexing – n Dimensions

VAR A : **ARRAY** $[l_1 .. h_1]$ ... $[l_n .. h_n]$ **OF** T;

$$w_k \equiv h_k - l_k + 1$$

$$C \equiv$$

$$\mathtt{A}_{\mathtt{addr}} - ((\cdots(l_1 * w_2 + l_2) * w_3 + l_3)\cdots) * w_n + l_n) * \mathtt{A}_{\mathtt{elsz}}$$

$$\mathtt{L} - \mathtt{VAL}(A[i_1, i_2, ..., i_n]) \equiv$$

$$((\cdots(i_1 * w_2 + i_2) * w_3 + i_3)\cdots) * w_n + i_n) * \mathtt{A}_{\mathtt{elsz}} + C$$

Record Types

- Pascal, C, Modula-2, Ada and other languages have variant records (C's union type):

```
TYPE R1 = RECORD tag :  (red,blue,green);
            CASE tag OF
                red :  r :  REAL; |
                blue :  i :  INTEGER; |
                ELSE c :  CHAR;
            END;
         END;
```

  Depending on the `tag` value `R1` has a real, integer, or char field.

- The size of a variant part is the max of the sizes of its constituent fields.

Record Types. . .

- Oberon has extensible record types:

```
TYPE R3 = RECORD
             a :  INTEGER;
          END;
TYPE R4 = (R3) RECORD
             b :  REAL;
          END;
```

  R4 has both the a and the b field.

- Extensible records are similar to classes in other languages.

Pointer Types

- In order to build recursive structures, most languages allow some way of declaring recursive types. These are necessary in order to construct linked structures such as lists and trees:

```
TYPE P = POINTER TO R;
TYPE R = RECORD
            data :  INTEGER;
            next :  P;
         END;
```

- Note that P is declared before its use. Languages such as Pascal and C don't allow forward declarations, but make an exception for pointers.

Procedure Types

- C, Modula-2, and other languages support procedure types. You can treat the address of a procedure like any other object.
- Languages differ in whether they allow procedures whose address is taken to be nested or not. (Why?)

```
TYPE P = PROCEDURE(x:INTEGER; VAR Y:CHAR):REAL;
VAR z :  P; VAR c :  CHAR; VAR r :  REAL;
PROCEDURE M (x:INTEGER; VAR Y:CHAR):REAL;
   BEGIN···END;
BEGIN
   z := M; /* z holds the address of M. */
   r := z(44,c);
END.
```

Class Types

- Java's classes are just pointer to record types. Some languages (Object Pascal, Oberon, MODULA-3) define classes just like records.
- Nore about classes later.

```
TYPE C1 = CLASS
             x :  INTEGER;
             void M() { ··· };
             void N() { ··· };
          END;
TYPE C2 = CLASS EXTENDS C1
             r :  REAL; // Add another field.
             void M() { ··· }; // Overrides C1.M
             void Q() { ··· }; // Add another method.
          END;
```

Set Types

- Pascal and Modula-2 support sets of ordinal types.
- Sets are implemented as bitvectors.
- Many implementations restrict the size of a set to 32 (the size of a machine word), or 256 (so you can declare a `set of char`).

```
type letset = set of 'A' ..  'z';
var x, y, z, w:  letset;
begin
   x := ['A'..'Z','a']; y := ['a'..'z'];
   z := x + y; (* set union *)
   z := x * y; (* set intersection *)
   w := x - y; (* set difference *)
   if 'A' in z then ...; (* set membership *)
end.
```

Readings and References

- Read Scott, pp. 312-320,336-361.