WEEK FOUR

Data Types

Chapter 6 Topics

- Introduction
- Primitive Data Types
- Character String Types
- User-Defined Ordinal Types
- Array Types
- Associative Arrays
- Record Types
- Union Types
- Pointer and Reference Types

Introduction

- A *data type* defines a collection of data values and a set of predefined operations on those values
- A *descriptor* is the collection of the attributes of a variable
- An *object* represents an instance of a user-defined (abstract data) type
- One design issue for all data types: What operations are defined and how are they specified?

Introduction

- Primitive data types
  - Integer *
  - Floating-point
  - Decimal
  - Character *
  - Boolean *
  - String / Array of Characters

* Ordinal type

- User-defined types
  - Enumeration *
  - Subrange *
  - Array
  - Associative array
  - Record
  - Variant record
  - Pointer
  - Reference type

Data Type in C#

- Value Type
  - Primitive (built-in value)
    - Integer : 8 types
    - Floating-point: 2 types
    - Decimal
    - Character
    - Boolean
  - User-defined
    - Enumeration
    - Struct
- Reference Type
  - String
  - Array
  - Pointer
  - Interface
  - Class
  - Delegate

Primitive Data Types

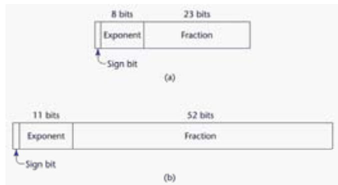
- Almost all programming languages provide a set of *primitive data types*
- Primitive data types: Those not defined in terms of other data types

Primitive Data Types: Integer

- Almost always an exact reflection of the hardware so the mapping is trivial
- There may be as many as eight different integer types in a language
- Java's signed integer sizes: `byte, short, int, long`

Primitive Data Types: Floating Point

- Model real numbers, but only as approximations
- Languages for scientific use support at least two floating-point types (e.g., `float` and `double`; sometimes more
- Usually exactly like the hardware, but not always
- IEEE Floating-Point Standard 754



Primitive Data Types: Decimal

- For business applications (money)
  - Essential to COBOL
  - C# offers a decimal data type
- Store a fixed number of decimal digits
- *Advantage*: accuracy
- *Disadvantages*: limited range, wastes memory

Primitive Data Types: Boolean

- Simplest of all
- Range of values: two elements, one for “true” and one for “false”
- Could be implemented as bits, but often as bytes
  - Advantage: readability

Primitive Data Types: Character

- Stored as numeric codings
- Most commonly used coding: ASCII
- An alternative, 16-bit coding: Unicode
  - Includes characters from most natural languages
  - Originally used in Java
  - C# and JavaScript also support Unicode

Character String Types

- Values are sequences of characters
- Design issues:
  - Is it a primitive type or just a special kind of array?
  - Should the length of strings be static or dynamic?

Character String Types Operations

- Typical operations:
  - Assignment and copying
  - Comparison (=, >, etc.)
  - Catenation
  - Substring reference
  - Pattern matching

Character String Type in Certain Languages

- C and C++
  - Not primitive
  - Use **`char`** arrays and a library of functions that provide operations
- SNOBOL4 (a string manipulation language)
  - Primitive
  - Many operations, including elaborate pattern matching
- Java
  - Primitive via the `String` class

Character String Length Options

- Static: COBOL, Java's `String` class
- *Limited Dynamic Length*: C and C++
  - In C-based language, a special character is used to indicate the end of a string's characters, rather than maintaining the length
- *Dynamic* (no maximum): SNOBOL4, Perl, JavaScript
- Ada supports all three string length options

Character String Type Evaluation

- Aid to writability
- As a primitive type with static length, they are inexpensive to provide--why not have them?
- Dynamic length is nice, but is it worth the expense?

User-Defined Ordinal Types

- An ordinal type is one in which the range of possible values can be easily associated with the set of positive integers
- Examples of primitive ordinal types in Java
  - `integer`
  - `char`
  - `boolean`

Enumeration Types

- All possible values, which are named constants, are provided in the definition
- C# example

```
enum days {mon, tue, wed, thu, fri, sat, sun};
```

- Design issues
  - Is an enumeration constant allowed to appear in more than one type definition, and if so, how is the type of an occurrence of that constant checked?
  - Are enumeration values coerced to integer?
  - Any other type coerced to an enumeration type?

Evaluation of Enumerated Type

- Aid to readability, e.g., no need to code a color as a number
- Aid to reliability, e.g., compiler can check:
  - operations (don't allow colors to be added)
  - No enumeration variable can be assigned a value outside its defined range
  - Ada, C#, and Java 5.0 provide better support for enumeration than C++ because enumeration type variables in these languages are not coerced into integer types

Subrange Types

- An ordered contiguous subsequence of an ordinal type
  - Example: 12..18 is a subrange of integer type
- Ada's design

```
type Days is (mon, tue, wed, thu, fri, sat, sun);
subtype Weekdays is Days range mon..fri;
subtype Index is Integer range 1..100;

Day1: Days;
Day2: Weekday;
Day2 := Day1;
```

Subrange Evaluation

- Aid to readability
  - Make it clear to the readers that variables of subrange can store only certain range of values
- Reliability
  - Assigning a value to a subrange variable that is outside the specified range is detected as an error

Array Types

- An array is an aggregate of homogeneous data elements in which an individual element is identified by its position in the aggregate, relative to the first element.

Array Design Issues

- What types are legal for subscripts?
- Are subscripting expressions in element references range checked?
- When are subscript ranges bound?
- When does allocation take place?
- What is the maximum number of subscripts?
- Can array objects be initialized?
- Are any kind of slices allowed?

Array Indexing

- *Indexing* (or subscripting) is a mapping from indices to elements
  `array_name (index_value_list) → an element`
- Index Syntax
  - FORTRAN, PL/I, Ada use parentheses
    - Ada explicitly uses parentheses to show uniformity between array references and function calls because both are *mappings*
  - Most other languages use brackets

Arrays Index (Subscript) Types

- FORTRAN, C: integer only
- Pascal: any ordinal type (integer, Boolean, char, enumeration)
- Ada: integer or enumeration (includes Boolean and char)
- Java: integer types only
- C, C++, Perl, and Fortran do not specify range checking
- Java, ML, C# specify range checking

Subscript Binding and Array Categories

- *Static*: subscript ranges are statically bound and storage allocation is static (before run-time)
  - Advantage: efficiency (no dynamic allocation)
- *Fixed stack-dynamic*: subscript ranges are statically bound, but the allocation is done at declaration time
  - Advantage: space efficiency

Subscript Binding and Array Categories (continued)

- *Stack-dynamic*: subscript ranges are dynamically bound and the storage allocation is dynamic (done at run-time)
  - Advantage: flexibility (the size of an array need not be known until the array is to be used)
- *Fixed heap-dynamic*: similar to fixed stack-dynamic: storage binding is dynamic but fixed after allocation (i.e., binding is done when requested and storage is allocated from heap, not stack)

Subscript Binding and Array Categories (continued)

- Heap-dynamic: binding of subscript ranges and storage allocation is dynamic and can change any number of times
  - Advantage: flexibility (arrays can grow or shrink during program execution)

Subscript Binding and Array Categories (continued)

- C and C++ arrays that include `static` modifier are static
- C and C++ arrays without `static` modifier are fixed stack-dynamic
- Ada arrays can be stack-dynamic
- C and C++ provide fixed heap-dynamic arrays
- C# includes a second array class `ArrayList` that provides fixed heap-dynamic
- Perl and JavaScript support heap-dynamic arrays

Array Initialization

- Some language allow initialization at the time of storage allocation
  - C, C++, Java, C# example

```
int list [] = {4, 5, 7, 83}
```

  - Character strings in C and C++

```
char name [] = “freddie”;
```

  - Arrays of strings in C and C++

```
char *names [] = {“Bob”, “Jake”, “Joe”];
```

  - Java initialization of String objects

```
String[] names = {“Bob”, “Jake”, “Joe”};
```


Arrays Operations

- APL provides the most powerful array processing operations for vectors and matrixes as well as unary operators (for example, to reverse column elements)
- Ada allows array assignment but also catenation
- Fortran provides *elemental* operations because they are between pairs of array elements
  - For example, + operator between two arrays results in an array of the sums of the element pairs of the two arrays

Slices

- A slice is some substructure of an array; nothing more than a referencing mechanism
- Slices are only useful in languages that have array operations

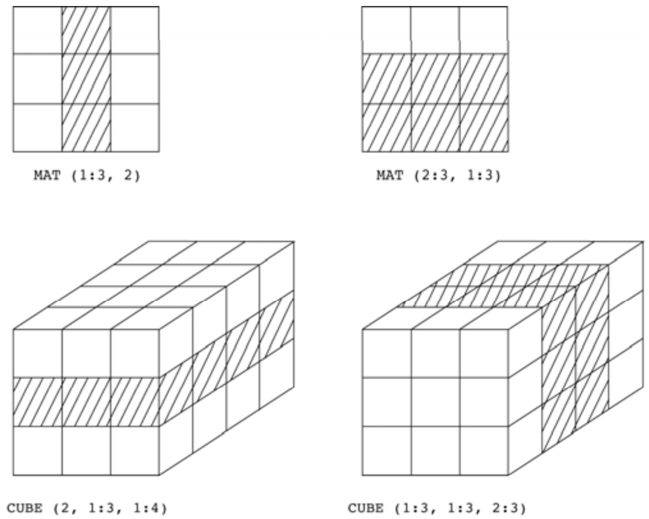
Slice Examples

- Fortran 95

```
Integer, Dimension (10) :: Vector
Integer, Dimension (3, 3) :: Mat
Integer, Dimension (3, 3) :: Cube
```

`Vector (3:6)` is a four element array

Slices Examples in Fortran 95



Accessing Multi-dimensioned Arrays

- Two common ways:
  - Row major order (by rows) – used in most languages
  - column major order (by columns) – used in Fortran

Associative Arrays

- An *associative array* is an unordered collection of data elements that are indexed by an equal number of values called *keys*
  - User defined keys must be stored
- Design issues: What is the form of references to elements

Associative Arrays in Perl

- Names begin with `%`; literals are delimited by parentheses

```
%hi_temps = ("Mon" => 77, "Tue" => 79,
  “Wed” => 65, …);
```

- Subscripting is done using braces and keys

```
$hi_temps{"Wed"} = 83;
```

  – Elements can be removed with `delete`

```
delete $hi_temps{"Tue"};
```


Record Types

- A *record* is a possibly heterogeneous aggregate of data elements in which the individual elements are identified by names
- Design issues:
  – What is the syntactic form of references to the field?
  – Are elliptical references allowed

Definition of Records

- COBOL uses level numbers to show nested records; others use recursive definition
- Record Field References

  1. COBOL

  field_name OF record_name_1 OF ... OF record_name_n

  2. Others (dot notation)

  record_name_1.record_name_2. ... record_name_n.field_name

Definition of Records in COBOL

- COBOL uses level numbers to show nested records; others use recursive definition

```
01 EMP-REC.
   02 EMP-NAME.
      05 FIRST PIC X(20).
      05 MID   PIC X(10).
      05 LAST  PIC X(20).
   02 HOURLY-RATE PIC 99V99.
```

Definition of Records in Ada

- Record structures are indicated in an orthogonal way

```
type Emp_Rec_Type is record
   First: String (1..20);
   Mid: String (1..10);
   Last: String (1..20);
   Hourly_Rate: Float;
end record;
Emp_Rec: Emp_Rec_Type;
```


References to Records

- Most language use dot notation
  `Emp_Rec.Name`
- Fully qualified references must include all record names
- Elliptical references allow leaving out record names as long as the reference is unambiguous, for example in COBOL
  `FIRST`, `FIRST OF EMP-NAME`, and `FIRST` of EMP-REC are elliptical references to the employee's first name

Operations on Records

- Assignment is very common if the types are identical
- Ada allows record comparison
- Ada records can be initialized with aggregate literals
- COBOL provides `MOVE CORRESPONDING`
  - Copies a field of the source record to the corresponding field in the target record

Evaluation and Comparison to Arrays

- Straight forward and safe design
- Records are used when collection of data values is heterogeneous
- Access to array elements is much slower than access to record fields, because subscripts are dynamic (field names are static)
- Dynamic subscripts could be used with record field access, but it would disallow type checking and it would be much slower

Unions Types

- A *union* is a type whose variables are allowed to store different type values at different times during execution
- Design issues
  - Should type checking be required?
  - Should unions be embedded in records?

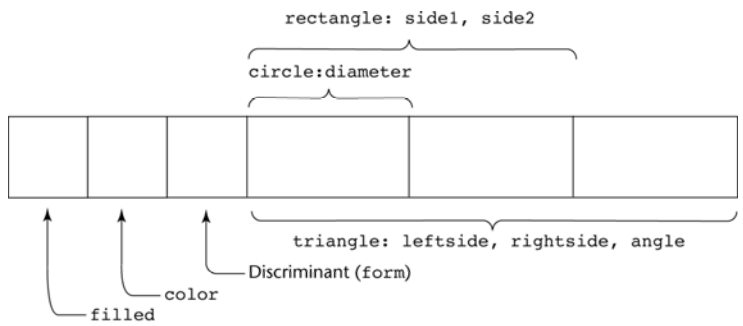
Discriminated vs. Free Unions

- Fortran, C, and C++ provide union constructs in which there is no language support for type checking; the union in these languages is called *free union*
- Type checking of unions require that each union include a type indicator called a *discriminant*
  - Supported by Ada

Ada Union Types

```
type Shape is (Circle, Triangle, Rectangle);
type Colors is (Red, Green, Blue);
type Figure (Form: Shape) is record
  Filled: Boolean;
  Color: Colors;
  case Form is
      when Circle => Diameter: Float;
      when Triangle =>
            Leftside, Rightside: Integer;
            Angle: Float;
      when Rectangle => Side1, Side2: Integer;
  end case;
end record;
```


Ada Union Type Illustrated



A discriminated union of three shape variables

Evaluation of Unions

- Potentially unsafe construct
  - Do not allow type checking
- Java and C# do not support unions
  - Reflective of growing concerns for safety in programming language

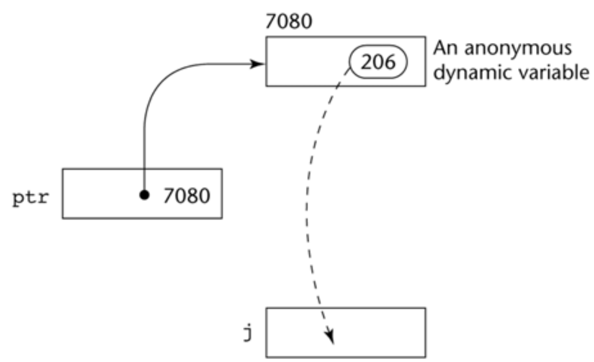
Pointer and Reference Types

- A *pointer* type variable has a range of values that consists of memory addresses and a special value, *nil*
- Provide the power of indirect addressing
- Provide a way to manage dynamic memory
- A pointer can be used to access a location in the area where storage is dynamically created (usually called a *heap*)

Pointer Operations

- Two fundamental operations: assignment and dereferencing
- Assignment is used to set a pointer variable's value to some useful address
- Dereferencing yields the value stored at the location represented by the pointer's value
  - Dereferencing can be explicit or implicit
  - C++ uses an explicit operation via *
    `j = *ptr`
    sets j to the value located at `ptr`

Pointer Assignment Illustrated



The assignment operation j = *ptr

Problems with Pointers

- Dangling pointers (dangerous)
  - A pointer points to a heap-dynamic variable that has been de-allocated
- Lost heap-dynamic variable
  - An allocated heap-dynamic variable that is no longer accessible to the user program (often called *garbage*)
    - Pointer `p1` is set to point to a newly created heap-dynamic variable
    - Pointer `p1` is later set to point to another newly created heap-dynamic variable

Pointers in C and C++

- Extremely flexible but must be used with care
- Pointers can point at any variable regardless of when it was allocated
- Used for dynamic storage management and addressing
- Pointer arithmetic is possible
- Explicit dereferencing and address-of operators
- Domain type need not be fixed (**`void *`**)
- `void *` can point to any type and can be type checked (cannot be de-referenced)

Pointer Arithmetic in C and C++

```
float stuff[100];
float *p;
p = stuff;
```

`*(p+5)` is equivalent to `stuff[5]` and `p[5]`
`*(p+i)` is equivalent to `stuff[i]` and `p[i]`

Reference Types

- C++ includes a special kind of pointer type called a *reference type* that is used primarily for formal parameters
  - Advantages of both pass-by-reference and pass-by-value
- Java extends C++'s reference variables and allows them to replace pointers entirely
  - References refer to call instances
- C# includes both the references of Java and the pointers of C++

Evaluation of Pointers

- Dangling pointers and dangling objects are problems as is heap management
- Pointers are like `goto`'s--they widen the range of cells that can be accessed by a variable
- Pointers or references are necessary for dynamic data structures--so we can't design a language without them

Summary

- The data types of a language are a large part of what determines that language's style and usefulness
- The primitive data types of most imperative languages include numeric, character, and Boolean types
- The user-defined enumeration and subrange types are convenient and add to the readability and reliability of programs
- Arrays and records are included in most languages
- Pointers are used for addressing flexibility and to control dynamic storage management

Assignment: hw4

- Data types in C, C++, C#
  - Primitive data types
    - name, range value, size (bits/bytes)
    - operations
  - User-defined data types
    - How to specify data types?
- Programming in C or C++
  - union & enumeration : calculate perimeter of circle, triangle, rectangle
  - array: initialize array of string, and access by using pointer and index
  - struct : array of students, input and display student information