UNIT-2

Data Types
Expressions and Statements

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CONCEPTS

Introduction

Names

Variables

The concept of binding

Scope

Scope and lifetime

Referencing Environments

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CONCEPTS

Introduction
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User-Defined Ordinal Types
Array Types
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Introduction

A *data type* defines a collection of data objects and a set of predefined operations on those objects

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?

Primitive Data Types

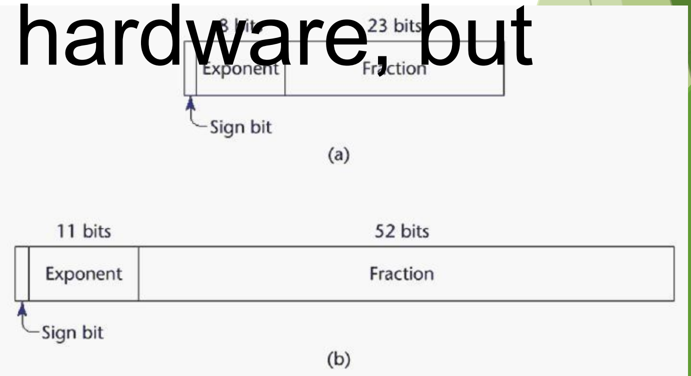
- Almost all programming languages provide a set of *primitive data types*
- Primitive data types: Those not defined in terms of other data types
- Some primitive data types are merely reflections of the hardware
- Others require only a little non-hardware
- support for their implementation

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: Complex

Some languages support a complex type, e.g., C99, Fortran, and Python

Each value consists of two floats, the real part and the imaginary part

Literal form (in Python):

`(7 + 3j)`, where `7` is the real part and `3` is the imaginary part

Primitive Data Types: Decimal

For business applications (money)

- Essential to COBOL
- C# offers a decimal data type

Store a fixed number of decimal digits, in coded form (BCD)

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 (UCS-2)
    - Includes characters from most natural languages
    - Originally used in Java
    - C# and JavaScript also support Unicode
- 32-bit Unicode (UCS-4)
  - – Supported by Fortran, starting with 2003

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

Fortran and Python

- Primitive type with assignment and several operations

Java

- Primitive via the `String` class

Perl, JavaScript, Ruby, and PHP

Provide built-in pattern matching, using regular expressions

Character String Length Options

- Static: COBOL, Java's `String` class
- *Limited Dynamic Length*: C and C++
  - In these languages, 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?

Character String Implementation

Static length: compile-time descriptor

Limited dynamic length: may need a run-time descriptor for length (but not in C and C++)

Dynamic length: need run-time descriptor; allocation/de-allocation is the biggest implementation problem

Compile- and Run-Time Descriptors

Static string
Length
Address

Compile-time descriptor for static strings

Limited dynamic string
Maximum length
Current length
Address

Run-time descriptor for limited dynamic strings

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

Implementation of User-Defined Ordinal Types

- Enumeration types are implemented as integers
- Subrange types are implemented like the parent types with code inserted (by the compiler) to restrict assignments to subrange variables

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 supported?

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
- Ada: integer or enumeration (includes Boolean and char) Java: integer types only
- Index range checking
  - C, C++, Perl, and Fortran do not specify
    - range checking
  - Java, ML, C# specify range checking
    - In Ada, the default is to require range checking, but it can be turned off

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
- C and C++ provide fixed heap-dynamic arrays
- C# includes a second array class `ArrayList` that provides fixed heap-dynamic
- Perl, JavaScript, Python, and Ruby 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"};
```

Heterogeneous Arrays

- A *heterogeneous array* is one in which the elements need not be of the same type
- Supported by Perl, Python, JavaScript, and Ruby

Array Initialization

C-based languages

- `int list [] = {1, 3, 5, 7}`
- `char *names [] = {"Mike", "Fred","Mary Lou"};`

Ada

- `List : array (1..5) of Integer :=`
  `(1 => 17, 3 => 34, others => 0);`

Python

- List comprehensions

```
list = [x ** 2 for x in range(12) if x % 3 ==
    0]
```

puts `[0, 9, 36, 81]` **in** `list`

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
- Python's array assignments, but they are only reference changes. Python also supports array catenation and element membership operations
- Ruby also provides array 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

Rectangular and Jagged Arrays

- A rectangular array is a multi-dimensioned array in which all of the rows have the same number of elements and all columns have the same number of elements
- A jagged matrix has rows with varying number of elements
  - Possible when multi-dimensioned arrays actually appear as arrays of arrays
- C, C++, and Java support jagged arrays
- Fortran, Ada, and C# support rectangular arrays (C# also supports jagged 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

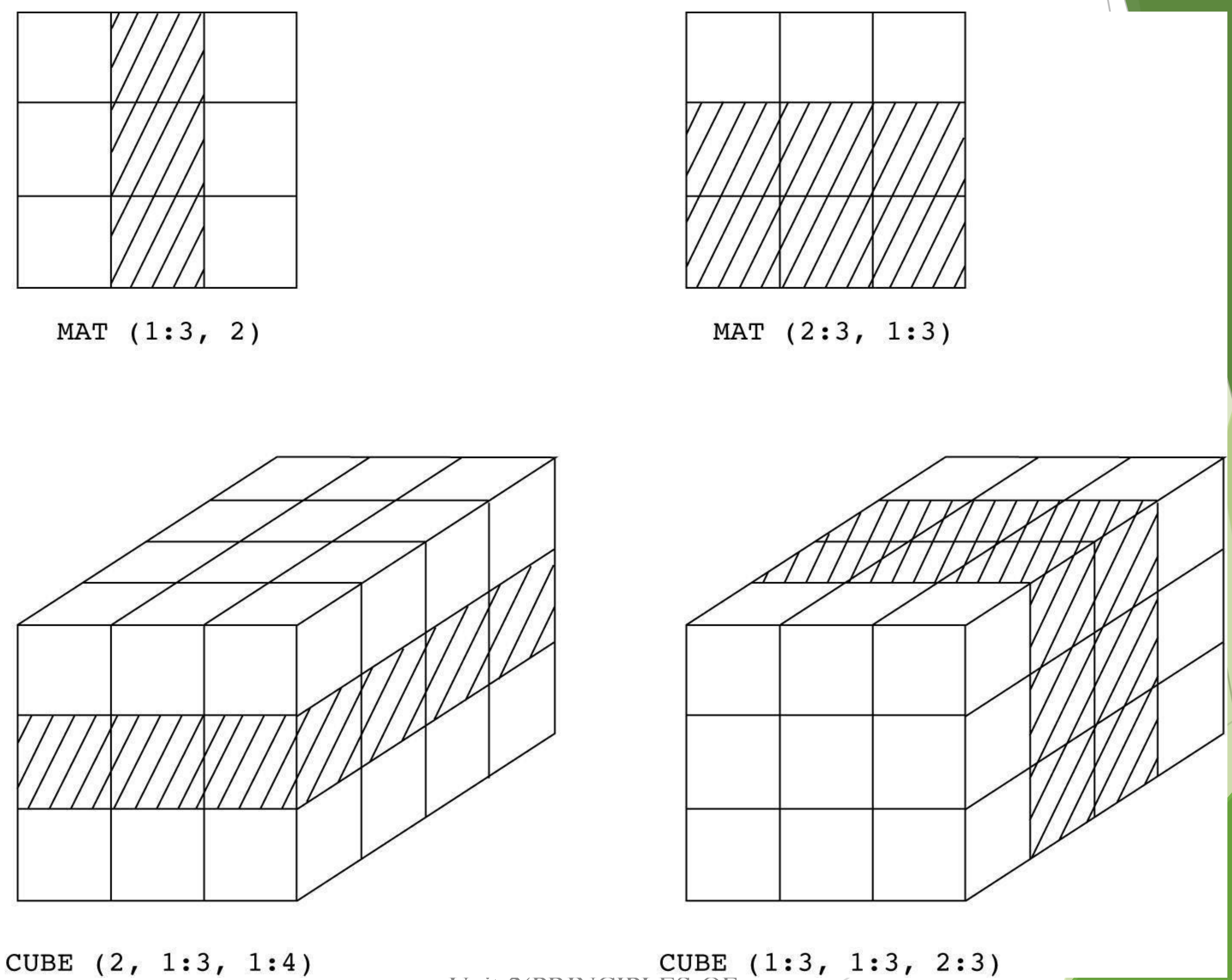
```
Integer, Dimension (10) :: Vector
Integer, Dimension (3, 3) :: Mat
Integer, Dimension (3, 3) :: Cube
```

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

Ruby supports slices with the `slice` method

`list.slice(2, 2)` returns the third and fourth elements of `list`

Slices Examples in Fortran 95



Implementation of Arrays

Access function maps subscript expressions to an address in the array

Access function for single-dimensioned arrays:

address(list[k]) = address (list[lower_bound])

((k-lower_bound) * element_size)

Accessing Multi-dimensioned Arrays

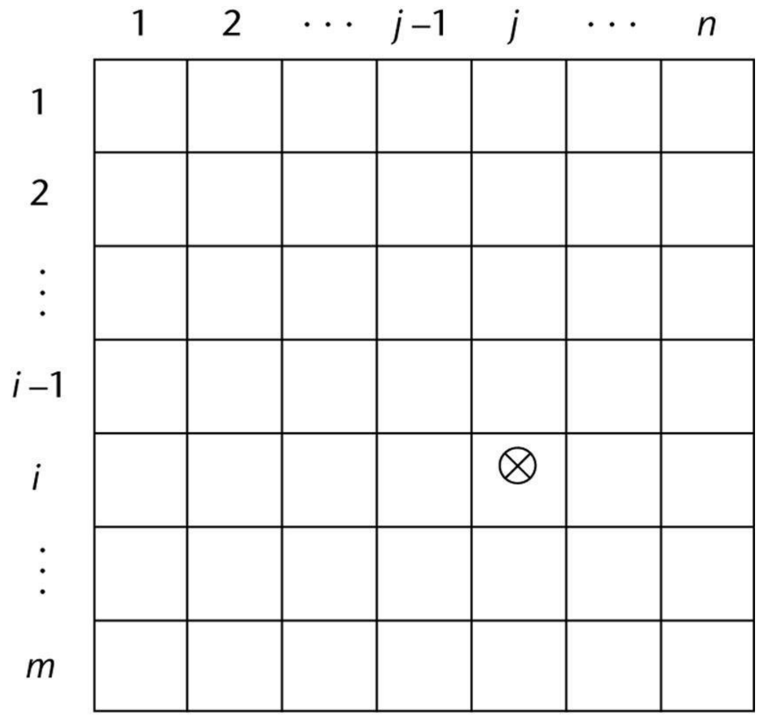
Two common ways:

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

Locating an Element in a Multi-dimensioned Array

- General format

  Location (a[I,j]) = address of a [row_lb,col_lb] + (((I - row_lb) * n) + (j - col_lb)) * element_size



Compile-Time Descriptors

Array
Element type
Index type
Index lower bound
Index upper bound
Address

Single-dimensioned array

Multidimensioned array
Element type
Index type
Number of dimensions
Index range 1
⋮
Index range *n*
Address

Multi-dimensional array

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?

Is the size static or dynamic?

Built-in type in Perl, Python, Ruby, and Lua

– In Lua, they are supported by tables

Associative Arrays in Perl

- Names begin with **%; l**iterals 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 in COBOL

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

```
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

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

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

Evaluation and Comparison to Arrays

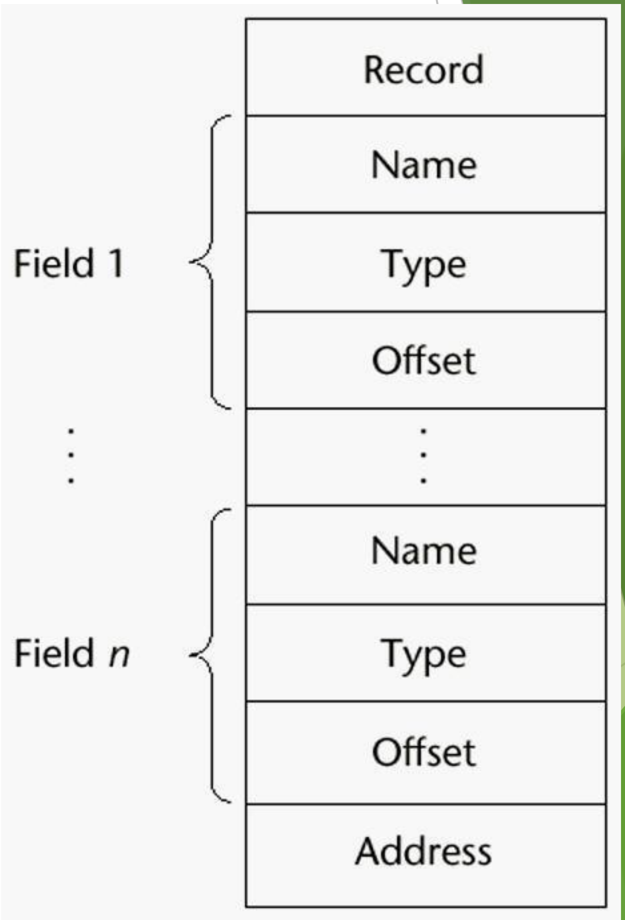
Records are used when collection of data values is heterogeneous

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

Implementation of Record Type

Offset address relative to the beginning of the records is associated with each field



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?

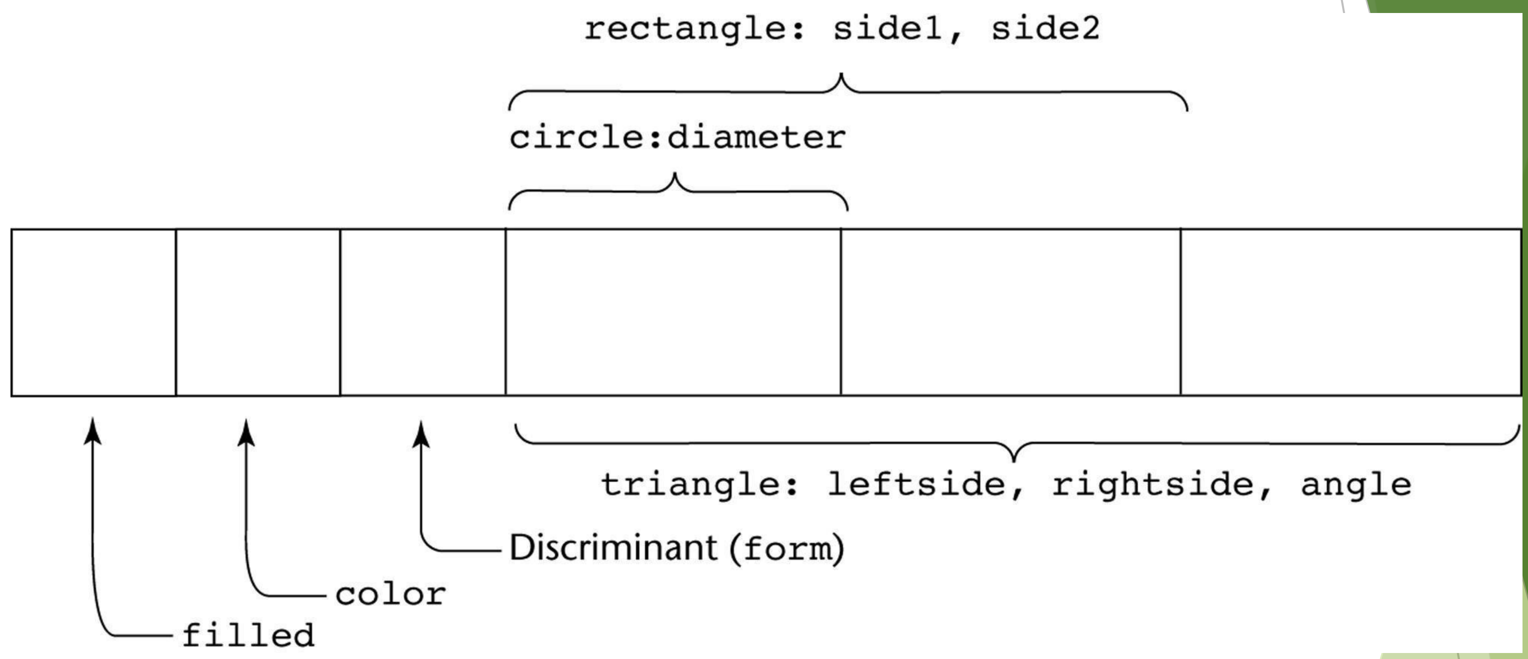
Discriminated vs. Free Unions

- 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

Free unions are unsafe

– Do not allow type checking

Java and C# do not support unions

– Reflective of growing concerns for safety in programming language

Ada's descriminated unions are safe

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

Design Issues of Pointers

- What are the scope of and lifetime of a pointer variable?
- What is the lifetime of a heap-dynamic
- variable?
- Are pointers restricted as to the type of value to which they can point?
- Are pointers used for dynamic storage management, indirect

Pointer Operations

Two fundamental operations: assignment and dereferencing

Assignment is used to set a pointer variable's value to some useful address

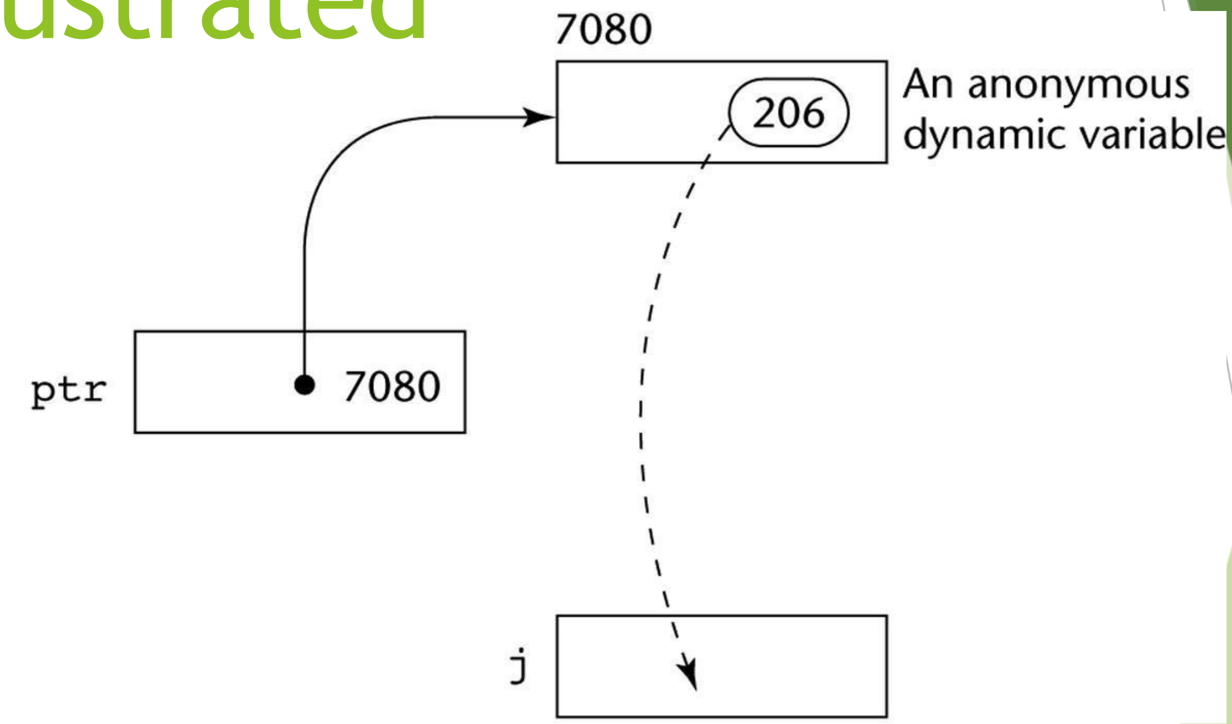
Dereferencing yields the value stored at the location represented by the pointer's value

- 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 deallocated

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

The process of losing heap-dynamic variables is called *memory leakage*

Pointers in Ada

- Some dangling pointers are disallowed because dynamic objects can be automatically deallocated at the end of pointer's type scope
- The lost heap-dynamic variable problem is not eliminated by Ada (possible with `UNCHECKED_DEALLOCATION`)

Pointers in C and C++

- Extremely flexible but must be used with care
- Pointers can point at any variable regardless of when or where 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 are references to objects, rather than being addresses
- 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

Representations of Pointers

Large computers use single values

Intel microprocessors use segment and offset

Dangling Pointer Problem

Tombstone: extra heap cell that is a pointer to the heap-dynamic variable

- The actual pointer variable points only at tombstones
- When heap-dynamic variable de-allocated, tombstone remains but set to nil
- Costly in time and space

. *Locks-and-keys*: Pointer values are represented as (key, address) pairs

- Heap-dynamic variables are represented as variable plus cell for integer lock value
- When heap-dynamic variable allocated, lock value is created and placed in lock cell and key cell of pointer

Heap Management

A very complex run-time process

Single-size cells vs. variable-size cells

Two approaches to reclaim garbage

- Reference counters (*eager approach*): reclamation is gradual
- Mark-sweep (*lazy approach*): reclamation occurs when the list of variable space becomes empty

Reference Counter

Reference counters: maintain a counter in every cell that store the number of pointers currently pointing at the cell

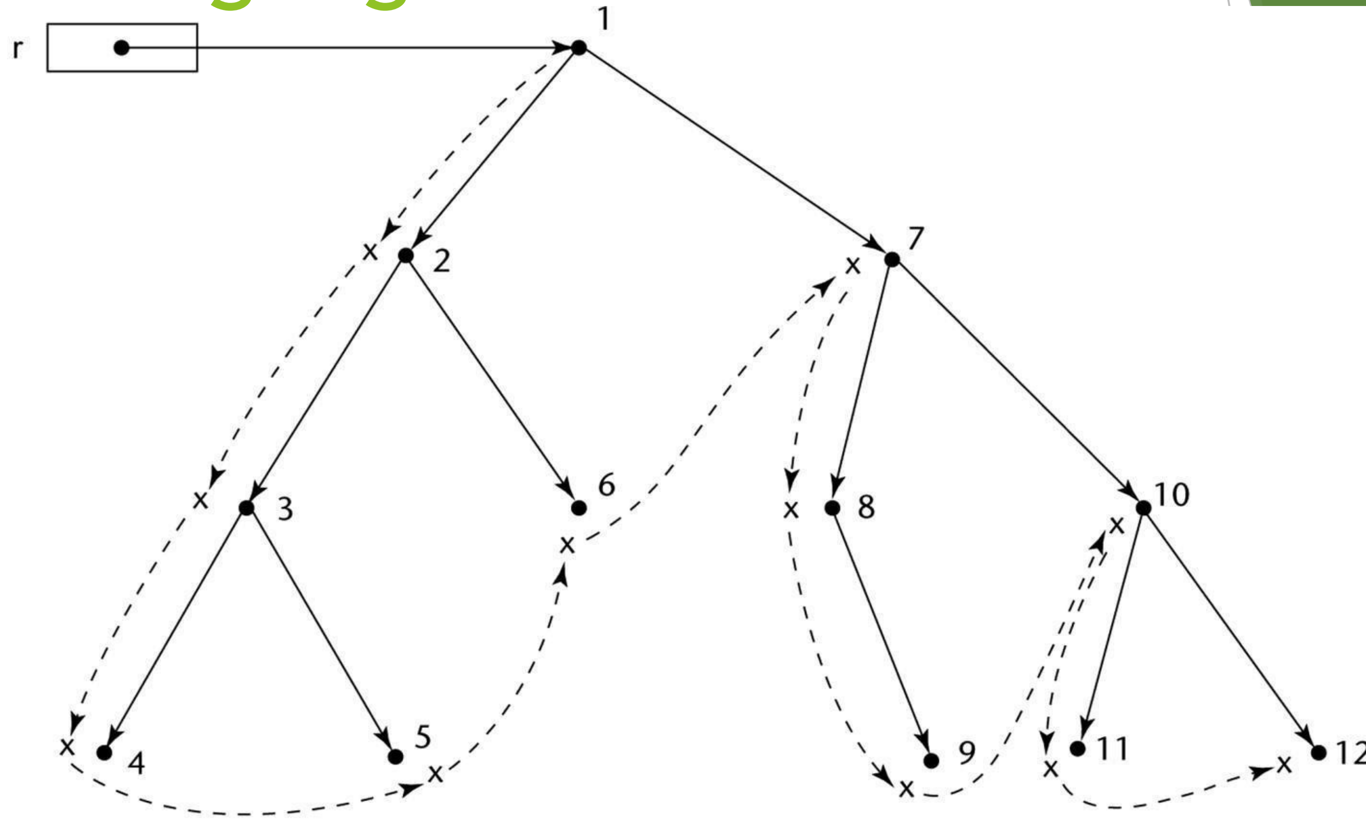
- *Disadvantages*: space required, execution time required, complications for cells connected circularly
- *Advantage*: it is intrinsically incremental, so significant delays in the application execution are avoided

Mark-Sweep

The run-time system allocates storage cells as requested and disconnects pointers from cells as necessary; mark-sweep then begins

- Every heap cell has an extra bit used by collection algorithm
- All cells initially set to garbage
- All pointers traced into heap, and reachable cells marked as not garbage
- All garbage cells returned to list of available cells
- Disadvantages: in its original form, it was done too infrequently. When done, it caused significant delays in application execution. Contemporary mark-sweep algorithms avoid this by doing it more often—called incremental mark-sweep

Marking Algorithm



Dashed lines show the order of node_marking

Variable-Size Cells

All the difficulties of single-size cells plus more

Required by most programming languages

If mark-sweep is used, additional problems occur

- The initial setting of the indicators of all cells in the heap is difficult
- The marking process in nontrivial
- Maintaining the list of available space is another source of overhead

Type Checking

Generalize the concept of operands and operators to include subprograms and assignments

Type checking is the activity of ensuring that the operands of an operator are of compatible types

A *compatible type* is one that is either legal for the operator, or is allowed under language rules to be implicitly converted, by compiler- generated code, to a legal type

– This automatic conversion is called a *coercion*.

A *type error* is the application of an operator to an operand of an inappropriate type

Type Checking
(continued)

- If all type bindings are static, nearly all type checking can be static
- If type bindings are dynamic, type checking must be dynamic
- A programming language is *strongly typed* if type errors are always detected
- Advantage of strong typing: allows the detection of the misuses of variables that result in type errors

Strong Typing

Language examples:

- FORTRAN 95 is not: parameters, `EQUIVALENCE`
- C and C++ are not: parameter type checking can be avoided; unions are not type checked
- Ada is, almost (`UNCHECKED CONVERSION` is loophole)

  (Java and C# are similar to Ada)

Strong Typing (continued)

Coercion rules strongly affect strong typing--they can weaken it considerably (C++ versus Ada)

Although Java has just half the assignment coercions of C++, its strong typing is still far less effective than that of Ada

Name Type Equivalence

Name type equivalence means the two variables have equivalent types if they are in either the same declaration or in declarations that use the same type name

Easy to implement but highly restrictive:

- Subranges of integer types are not equivalent with integer types
- Formal parameters must be the same type as their corresponding actual parameters

Structure Type Equivalence

Structure type equivalence means that two variables have equivalent types if their types have identical structures

More flexible, but harder to implement

Type Equivalence (continued)

Consider the problem of two structured types:

– Are two record types equivalent if they are structurally the same but use different field names?

– Are two array types equivalent if they are the same except that the subscripts are different? (e.g. [1..10] and [0..9])

– Are two enumeration types equivalent if their components are spelled differently?

– With structural type equivalence, you cannot differentiate between types of the same structure (e.g. different units of speed, both float)

Theory and Data Types

Type theory is a broad area of study in mathematics, logic, computer science, and philosophy

Two branches of type theory in computer science:

- Practical – data types in commercial languages
- Abstract – typed lambda calculus

A type system is a set of types and the rules that govern their use in programs

Theory and Data Types
(continued)

Formal model of a type system is a set of types and a collection of functions that define the type rules

- Either an attribute grammar or a type map could be used for the functions
- Finite mappings – model arrays and functions
- Cartesian products – model tuples and records
- Set unions – model union types
- Subsets – model subtypes

Introduction

Imperative languages are abstractions of von Neumann architecture

– Memory

– Processor

Variables characterized by attributes

– To design a type, must consider scope, lifetime, type checking, initialization, and type compatibility

Names

Design issues for names:

– Are names case sensitive?

– Are special words reserved words or keywords?

Names (continued)

Length

– If too short, they cannot be connotative

– Language examples:

FORTRAN 95: maximum of 31

C99: no limit but only the first 63 are significant; also, external names are limited to a maximum of 31

C#, Ada, and Java: no limit, and all are significant

C++: no limit, but implementers often impose one

Names (continued)

Special characters

- PHP: all variable names must begin with dollar signs
- Perl: all variable names begin with special characters, which specify the variable's type
- Ruby: variable names that begin with `@` are instance variables; those that begin with `@@` are class variables

Names (continued)

Case sensitivity

– Disadvantage: readability (names that look alike are different)

Names in the C-based languages are case sensitive

Names in others are not

Worse in C++, Java, and C# because predefined names
are mixed case (e.g. `IndexOutOfBoundsException`)

Names (continued)

Special words

- An aid to readability; used to delimit or separate statement clauses

  A *keyword* is a word that is special only in certain contexts, e.g., in Fortran

  - `Real VarName` (`Real` *is a data type followed with a name, therefore* `Real` *is a keyword)*
  - `Real = 3.4` (*`Real` is a variable)*
- A *reserved word* is a special word that cannot be used as a user-defined name
- Potential problem with reserved words: If there are too many, many collisions occur (e.g., COBOL has 300 reserved words!)

Variables

A variable is an abstraction of a memory cell
Variables can be characterized as a sextuple of attributes:

- Name
- Address
- Value
- Type
- Lifetime
- Scope

Variables Attributes

Name - not all variables have them

Address - the memory address with which it is associated

- A variable may have different addresses at different times during execution
- A variable may have different addresses at different places in a program
- If two variable names can be used to access the same memory location, they are called aliases
- Aliases are created via pointers, reference variables, C and C++ unions
- Aliases are harmful to readability (program readers must remember all of them)

Variables Attributes (continued)

- *Type* - determines the range of values of variables and the set of operations that are defined for values of that type; in the case of floating point, type also determines the precision
- *Value* - the contents of the location with which the variable is associated
- The l-value of a variable is its address The r-value of a variable

  is its value
- *Abstract memory cell* - the physical cell or collection of cells associated with a variable

The Concept of Binding

- A *binding* is an association, such as between an attribute and an entity, or between an operation and a symbol
- *Binding time* is the time at which a binding
- takes place.

Possible Binding Times

Language design time -- bind operator symbols to operations

Language implementation time-- bind floating point type to a representation

Compile time -- bind a variable to a type in C or Java

Load time -- bind a C or C++ `static` variable to a memory cell)

Runtime -- bind a nonstatic local variable to a memory cell

Static and Dynamic Binding

- A binding is *static* if it first occurs before run time and remains unchanged throughout program execution.
- A binding is *dynamic* if it first occurs during execution or can change during execution of the program

Type Binding

- How is a type specified?
- When does the binding take place?
- If static, the type may be specified by either
  - an explicit or an implicit declaration

Explicit/Implicit Declaration

An *explicit declaration* is a program statement used for declaring the types of variables

An *implicit declaration* is a default mechanism for specifying types of variables (the first appearance of the variable in the program)

FORTRAN, BASIC, and Perl provide implicit declarations (Fortran has both explicit and implicit)

- Advantage: writability
- Disadvantage: reliability (less trouble with Perl)

Dynamic Type Binding

Dynamic Type Binding (JavaScript and PHP)
Specified through an assignment statement
e.g., JavaScript

```
list = [2, 4.33, 6, 8];
list = 17.3;
```

- Advantage: flexibility (generic program units)
- Disadvantages:
  - High cost (dynamic type checking and interpretation)
  - Type error detection by the compiler is difficult

Variable Attributes (continued)

- Type Inferencing (ML, Miranda, and Haskell)
  – Rather than by assignment statement, types are determined (by the compiler) from the context of the reference
- Storage Bindings & Lifetime
  – Allocation - getting a cell from some pool of available cells
  – Deallocation - putting a cell back into the pool
- The lifetime of a variable is the time during which it is bound to a particular memory cell

Categories of Variables by Lifetimes

- Static--bound to memory cells before execution begins and remains bound to the same memory cell throughout execution, e.g., C and C++ `static` variables
  - Advantages: efficiency (direct addressing), history-sensitive subprogram support
  - Disadvantage: lack of flexibility (no recursion)

Categories of Variables by **Lifetimes**

Stack-dynamic--Storage bindings are created for variables when their declaration statements are *elaborated*.

(A declaration is elaborated when the executable code associated with it is executed)

If scalar, all attributes except address are statically bound

– local variables in C subprograms and Java methods

Advantage: allows recursion; conserves storage

Disadvantages:

- Overhead of allocation and deallocation
- Subprograms cannot be history sensitive
- Inefficient references (indirect addressing)

Categories of Variables by Lifetimes

- *Explicit heap-dynamic* -- Allocated and deallocated by explicit directives, specified by the programmer, which take effect during execution
- Referenced only through pointers or references, e.g. dynamic objects in C++ (via `new` and `delete`), all objects in Java

- Advantage: provides for dynamic storage management Disadvantage: inefficient and unreliable

Categories of Variables by Lifetimes

- *Implicit heap-dynamic*--Allocation and deallocation caused by assignment statements
  – all variables in APL; all strings and arrays in Perl, JavaScript, and PHP
- Advantage: flexibility (generic code)
- Disadvantages:
  – Inefficient, because all attributes are dynamic
  – Loss of error detection

Variable Attributes: Scope

- The *scope* of a variable is the range of statements over which it is visible
- The *nonlocal variables* of a program unit are those that are visible but not declared there
- The scope rules of a language determine how references to names are associated with variables

Static Scope

Based on program text

To connect a name reference to a variable, you (or the compiler) must find the declaration

Search process: search declarations, first locally, then in increasingly larger enclosing scopes, until one is found for the given name

Enclosing static scopes (to a specific scope) are called its *static ancestors*; the nearest static ancestor is called a *static parent*

Some languages allow nested subprogram definitions, which create nested static scopes (e.g., Ada, JavaScript, Fortran 2003, and PHP)

Scope (continued)

- Variables can be hidden from a unit by having a "closer" variable with the same name
- Ada allows access to these "hidden" variables
  - – E.g., **`unit.name`**

Blocks

- A method of creating static scopes inside program units--from ALGOL 60
- Example in C:

```
void sub() {
  int count;
  while (...) {
      int count;
    count++;
    ...
  }
  …
}
```

```
Note: legal in C and C++, but not in
      Java and C# - too error-prone
```

Declaration Order

C99, C++, Java, and C# allow variable declarations to appear anywhere a statement can appear

– In C99, C++, and Java, the scope of all local variables is from the declaration to the end of the block

– In C#, the scope of any variable declared in a block is the whole block, regardless of the position of the declaration in the block

However, a variable still must be declared before it can be used

Declaration Order (continued)

- In C++, Java, and C#, variables can be declared in `for` statements
  - The scope of such variables is restricted to the `for` construct

Global Scope

C, C++, PHP, and Python support a program structure that consists of a sequence of function definitions in a file

– These languages allow variable declarations to appear outside function definitions

C and C++have both declarations (just attributes) and definitions (attributes and storage)

– A declaration outside a function definition specifies that it is defined in another file

Global Scope (continued)

PHP

- Programs are embedded in XHTML markup documents, in any number of fragments, some statements and some function definitions
- The scope of a variable (implicitly) declared in a function is local to the function
- The scope of a variable implicitly declared outside functions is from the declaration to the end of the program, but skips over any intervening functions

Global variables can be accessed in a function through the `$GLOBALS` array or by declaring it `global`

Global Scope (continued)

Python

– A global variable can be referenced in functions, but can be assigned in a function only if it has been declared to be `global` in the function

Evaluation of Static Scoping

Works well in many situations

Problems:

- In most cases, too much access is possible
- As a program evolves, the initial structure is destroyed and local variables often become global; subprograms also gravitate toward become global, rather than nested

Dynamic Scope

Based on calling sequences of program units, not their textual layout (temporal versus spatial)

References to variables are connected to declarations by searching back through the chain of subprogram calls that forced execution to this point

Scope Example

Static scoping

– Reference to X is to Big's X

Dynamic scoping

– Reference to X is to Sub1's X

Evaluation of Dynamic Scoping:

– Advantage: convenience

– *Disadvantages*:

While a subprogram is executing, its variables are visible to all subprograms it calls

Impossible to statically type check

Poor readability- it is not possible to statically determine the type of a variable

Scope and Lifetime

- Scope and lifetime are sometimes closely related, but are different concepts
- Consider a `static` variable in a C or C++ function

Referencing Environments

- The *referencing environment* of a statement is the collection of all names that are visible in the statement
- In a static-scoped language, it is the local variables plus all of the visible variables in all of the enclosing scopes
- A subprogram is active if its execution has begun but has not yet terminated
- In a dynamic-scoped language, the referencing environment is the local variables plus all visible variables in all active subprograms

Named Constants

A *named constant* is a variable that is bound to a value only when it is bound to storage

Advantages: readability and modifiability

Used to parameterize programs

The binding of values to named constants can be either static (called *manifest constants*) or dynamic

Languages:

- FORTRAN 95: constant-valued expressions
- Ada, C++, and Java: expressions of any kind
- C# has two kinds, `readonly` and `const`

  the values of `const` named constants are bound at compile time

  The values of `readonly` named constants are dynamically bound

Summary

- Case sensitivity and the relationship of names to special words represent design issues of names
- Variables are characterized by the sextuples: name, address, value, type, lifetime, scope
- Binding is the association of attributes with program entities
- Scalar variables are categorized as: static, stack dynamic, explicit heap dynamic, implicit heap dynamic
- Strong typing means detecting all type

Introduction

Arithmetic Expressions

Overloaded Operators

Type Conversions

Relational and Boolean Expressions

Short-Circuit Evaluation

Assignment Statements

Mixed-Mode Assignment

Introduction

Expressions are the fundamental means of specifying computations in a programming language

To understand expression evaluation, need to be familiar with the orders of operator and operand evaluation

Essence of imperative languages is dominant role of assignment statements

Arithmetic Expressions

- Arithmetic evaluation was one of the motivations for the development of the first programming languages
- Arithmetic expressions consist of operators,
- operands, parentheses, and function calls

Arithmetic Expressions: Design Issues

Design issues for arithmetic expressions

- Operator precedence rules?
- Operator associativity rules?
- Order of operand evaluation?
- Operand evaluation side effects?
- Operator overloading?
- Type mixing in expressions?

Arithmetic Expressions: Operators

A unary operator has one operand

A binary operator has two operands

A ternary operator has three operands

Arithmetic Expressions: Operator Precedence Rules

The *operator precedence rules* for expression evaluation define the order in which "adjacent" operators of different precedence levels are evaluated

Typical precedence levels

– parentheses
– unary operators
– ** (if the language supports it)
– *, /
– +, -

Arithmetic Expressions: Operator Associativity

Rule

- The *operator associativity rules* for expression evaluation define the order in which adjacent operators with the same precedence level are evaluated
- Typical associativity rules
  - Left to right, except **, which is right to left
  - Sometimes unary operators associate right to left (e.g., in FORTRAN)
- APL is different; all operators have equal precedence and all operators associate right to left
- Precedence and associativity rules can be overriden with

Ruby Expressions

All arithmetic, relational, and assignment operators, as well as array indexing, shifts, and bit-wise logic operators, are implemented as methods

One result of this is that these operators can all be overriden by application programs

Arithmetic Expressions: Conditional Expressions

Conditional Expressions

- C-based languages (e.g., C, C++)
- An example:

```
average = (count == 0)? 0 : sum / count
```

- Evaluates as if written like

```
if (count == 0)
   average = 0
else
   average = sum /count
```

Arithmetic Expressions: Operand Evaluation Order

Operand evaluation order

- Variables: fetch the value from memory
- Constants: sometimes a fetch from memory; sometimes the constant is in the machine language instruction
- Parenthesized expressions: evaluate all operands and operators first
- The most interesting case is when an operand is a function call

Arithmetic Expressions: Potentials for Side Effects

Functional side effects: when a function changes a two-way parameter or a non-local variable

Problem with functional side effects:

– When a function referenced in an expression alters another operand of the expression; e.g., for a parameter change:

```
a = 10;
/* assume that fun changes its parameter */
b = a + fun(&a);
```

Functional Side Effects

Two possible solutions to the problem

- Write the language definition to disallow functional side effects
  - No two-way parameters in functions
  - No non-local references in functions
  - **Advantage:** it works!
  - **Disadvantage:** inflexibility of one-way parameters and lack of non-local references
- Write the language definition to demand that operand evaluation order be fixed
  - **Disadvantage**: limits some compiler optimizations
  - Java requires that operands appear to be evaluated in left-to-right order

Overloaded Operators

Use of an operator for more than one purpose is called *operator overloading*

Some are common (e.g., + for `int` and `float`)

Some are potential trouble (e.g., `*` in C and C++)

- Loss of compiler error detection (omission of an operand should be a detectable error)
- Some loss of readability

Overloaded Operators (continued)

C++ and C# allow user-defined overloaded operators

Potential problems:

- Users can define nonsense operations
- Readability may suffer, even when the operators make sense

Type Conversions

A *narrowing conversion* is one that converts an object to a type that cannot include all of the values of the original type e.g., `float` to `int`

A *widening conversion* is one in which an object is converted to a type that can include at least approximations to all of the values of the original type e.g., `int` to `float`

Type Conversions: Mixed Mode

- A *mixed-mode expression* is one that has operands of different types
- A *coercion* is an implicit type conversion
- Disadvantage of coercions:
  - They decrease in the type error detection ability of the compiler
- In most languages, all numeric types are coerced in expressions, using widening conversions
- In Ada, there are virtually no coercions in expressions

Explicit Type Conversions

Called *casting* in C-based languages

Examples

– C: `(int)angle`

– Ada: `Float (Sum)`

Note that Ada's syntax is similar to that of function calls

Type Conversions: Errors in Expressions

Causes

- Inherent limitations of arithmetic e.g., division by zero
- Limitations of computer arithmetice.g. overflow

Often ignored by the run-time system

Relational and Boolean Expressions

Relational Expressions

– Use relational operators and operands of various types
– Evaluate to some Boolean representation
– Operator symbols used vary somewhat among languages (`!=`, `/=`, `~=`, `.NE.`, `<>`, `#`)

JavaScript and PHP have two additional relational operator, `===` and `!==`

Similar to their cousins, `==` and `!=`, except that they do not coerce their operands

Relational and Boolean Expressions

Boolean Expressions

- Operands are Boolean and the result is Boolean
- Example operators

FORTRAN 77	FORTRAN 90	C	Ada
.AND.	and	&&	and
.OR.	or	||	or
.NOT.	not	!	not
			xor

Relational and Boolean Expressions: No Boolean Type in C

- C89 has no Boolean type--it uses `int` type with 0 for false and nonzero for true
- One odd characteristic of C's expressions: **`a < b < c`** is a legal expression, but the result is not what you might expect:
  - Left operator is evaluated, producing 0 or 1
  - The evaluation result is then compared with the third operand (i.e., **`c`**)

Short Circuit Evaluation

An expression in which the result is determined without evaluating all of the operands and/or operators

Example: **`(13*a) * (b/13–1)`**

If `a` is zero, there is no need to evaluate **`(b/13-1)`**

Problem with non-short-circuit evaluation

```
index = 1;
while (index <= length) && (LIST[index] !=
          value) index++;
```

– When **`index=length`**, **`LIST [index]`** will cause an indexing problem (assuming **`LIST`** has **`length -1`** elements)

Short Circuit Evaluation (continued)

C, C++, and Java: use short-circuit evaluation for the usual Boolean operators (**&&** and **||**), but also provide bitwise Boolean operators that are not short circuit (**&** and **|**)

Ada: programmer can specify either (short-circuit is specified with **and then** and **or else**)

Short-circuit evaluation exposes the potential problem of side effects in expressions
e.g. **(a > b) || (b++ / 3)**

Assignment Statements

The general syntax

```
<target_var> <assign_operator> <expression>
```

The assignment operator

FORTRAN, BASIC, the C-based languages	=
:=	ALGOLs, Pascal, Ada

= can be bad when it is overloaded for the relational operator for equality (that's why the C-based languages use == as the relational operator)

Assignment Statements: Conditional Targets

Conditional targets (Perl)

```
($flag ? $total : $subtotal) = 0
```

Which is equivalent to

```
if ($flag){
  $total = 0
} else {
  $subtotal = 0
}
```

Assignment Statements: Compound Operators

A shorthand method of specifying a commonly needed form of assignment

Introduced in ALGOL; adopted by C

Example

```
a = a + b
```

is written as

```
a += b
```

Assignment Statements: Unary Assignment Operators

Unary assignment operators in C-based languages combine increment and decrement operations with assignment

Examples

- `sum = ++count` (`count` incremented, added to `sum`)
- `sum = count++` (`count` incremented, added to `sum`)
- `count++` (`count` incremented)
- `-count++` (`count` incremented then negated)

Assignment as an Expression

In C, C++, and Java, the assignment statement produces a result and can be used as operands

An example:

```
while ((ch = getchar())!= EOF){…}
```

`ch = getchar()` is carried out; the result (assigned to `ch`) is used as a conditional value for the `while` statement

List Assignments

Perl and Ruby support list assignments

e.g.,

```
($first, $second, $third) = (20, 30, 40);
```

Mixed-Mode Assignment

Assignment statements can also be mixed-mode

In Fortran, C, and C++, any numeric type value can be assigned to any numeric type variable

In Java, only widening assignment coercions are done

In Ada, there is no assignment coercion

Summary

Expressions

Operator precedence and associativity

Operator overloading

Mixed-type expressions

Various forms of assignment

Introduction

Selection Statements

Iterative Statements

Unconditional Branching

Guarded Commands

Conclusions

Levels of Control Flow

- Within expressions (Chapter 7)
- Among program units (Chapter 9)
- Among program statements (this chapter)

Control Statements: Evolution

- FORTRAN I control statements were based directly on IBM 704 hardware
- Much research and argument in the 1960s about the issue
  – One important result: It was proven that all algorithms represented by flowcharts can be coded with only two-way selection and pretest logical loops

Control Structure

- A *control structure* is a control statement and the statements whose execution it controls
- Design question
  - – Should a control structure have multiple entries?

Selection Statements

A *selection statement* provides the means of choosing between two or more paths of execution

Two general categories:

- Two-way selectors
- Multiple-way selectors

Two-Way Selection Statements

General form:

```
if control_expression
  then clause
  else clause
```

Design Issues:

- What is the form and type of the control expression?
- How are the **`then`** and **`else`** clauses specified?
- How should the meaning of nested selectors be specified?

The Control Expression

If the then reserved word or some other syntactic marker is not used to introduce the then clause, the control expression is placed in parentheses

In C89, C99, Python, and C++, the control expression can be arithmetic

In languages such as Ada, Java, Ruby, and C#, the control expression must be Boolean

Clause Form

- In many contemporary languages, the then and else clauses can be single statements or compound statements
- In Perl, all clauses must be delimited by braces (they must be compound)
- In Fortran 95, Ada, and Ruby, clauses are statement sequences
- Python uses indentation to define clauses
  - i
    f
    x
    >

Nesting Selectors

Java example

```
if (sum == 0)
   if (count == 0)
       result = 0;
else result = 1;
```

Which `if` gets the `else`?

Java's static semantics rule: `else` matches with the nearest `if`

Nesting Selectors (continued)

To force an alternative semantics, compound statements may be used:

```
if (sum == 0) {
  if (count == 0)
      result = 0;
}
else result = 1;
```

The above solution is used in C, C++, and C#

Perl requires that all then and else clauses to be compound

Nesting Selectors (continued)

Statement sequences as clauses: Ruby

```
if sum == 0 then
  if count == 0 then
    result = 0
  else
    result = 1
  end
end
```

Nesting Selectors (continued)

Python

```
if sum == 0 :
   if count == 0 :
      result = 0
   else :
      result = 1
```

Multiple-Way Selection Statements

Allow the selection of one of any number of statements or statement groups

Design Issues:

- What is the form and type of the control expression?
- How are the selectable segments specified?
- Is execution flow through the structure restricted to include just a single selectable segment?
- How are case values specified?
- What is done about unrepresented expression values?

Multiple-Way Selection: Examples

- C, C++, and Java
  - `switch (expression) {`
    - `case const_expr_1: stmt_1;`
    - …
    - `case const_expr_n: stmt_n;`
    - `[default: stmt_n+1]`
  - `}`

Multiple-Way Selection: Examples

Design choices for C's **`switch`** statement

- Control expression can be only an integer type
- Selectable segments can be statement sequences, blocks, or compound statements
- Any number of segments can be executed in one execution of the construct (there is no implicit branch at the end of selectable segments)
- **`default`** clause is for unrepresented values (if there is no **`default`**, the whole statement does nothing)

Multiple-Way Selection: Examples

C#

- Differs from C in that it has a static semantics rule that disallows the implicit execution of more than one segment
- Each selectable segment must end with an unconditional branch (`goto` or `break`)
- Also, in C# the control expression and the case constants can be strings

Multiple-Way Selection: Examples

Ada

```
case expression is
    when choice list => stmt_sequence;
    …
    when choice list => stmt_sequence;
    when others => stmt_sequence;]
end case;
```

More reliable than C's `switch` (once a stmt_sequence execution is completed, control is passed to the first statement after the `case` statement

Multiple-Way Selection: Examples

Ada design choices:

Expression can be any ordinal type

Segments can be single or compound

Only one segment can be executed per execution of the construct

Unrepresented values are not allowed

Constant List Forms:

A list of constants

Can include:

- Subranges
- Boolean OR operators (|)

Multiple-Way Selection: Examples

Ruby has two forms of case statements

1. One form uses when conditions

```
leap = case
       when year % 400 == 0 then true
       when year % 100 == 0 then
       false else year % 4 == 0
       end
```

2. The other uses a case value and when values

```
case in_val
when -1 then neg_count++
when 0 then zero_count++
when 1 then pos_count++
else puts "Error – in_val is out of range"
end
```

Multiple-Way Selection Using `if`

Multiple Selectors can appear as direct extensions to two-way selectors, using else-if clauses, for example in Python:

```
if count < 10 :
  bag1 = True
elif count < 100 :
  bag2 = True
elif count < 1000 :
  bag3 = True
```

Multiple-Way Selection Using `if`

- The Python example can be written as a Ruby
  - `case`
- `case`
  - `when count < 10 then bag1 = true when count < 100 then bag2 = true when count < 1000 then bag3 = true`
- `end`

Iterative Statements

The repeated execution of a statement or compound statement is accomplished either by iteration or recursion

General design issues for iteration control statements:

- How is iteration controlled?
- Where is the control mechanism in the loop?

Counter-Controlled Loops

A counting iterative statement has a loop variable, and a means of specifying the *initial* and *terminal*, and *stepsize* values

Design Issues:

- What are the type and scope of the loop variable?
- Should it be legal for the loop variable or loop parameters to be changed in the loop body, and if so, does the change affect loop control?
- Should the loop parameters be evaluated only once, or once for every iteration?

Iterative Statements: Examples

FORTRAN 95 syntax

```
DO label var = start, finish [, stepsize]
```

Stepsize can be any value but zero

Parameters can be expressions

Design choices:

- Loop variable must be **INTEGER**
- The loop variable cannot be changed in the loop, but the parameters can; because they are evaluated only once, it does not affect loop control
- Loop parameters are evaluated only once

Iterative Statements: Examples

FORTRAN 95 : a second form:

```
[name:] Do variable = initial, terminal [,stepsize]
                 …
End Do [name]
```

- Cannot branch into either of Fortran's `Do` statements

Iterative Statements: Examples

Ada

```
for var in [reverse] discrete_range loop
...
end loop
```

Design choices:

Type of the loop variable is that of the discrete range (A discrete range is a sub-range of an integer or enumeration type).

Loop variable does not exist outside the loop

The loop variable cannot be changed in the loop, but the discrete range can; it does not affect loop control

The discrete range is evaluated just once

Cannot branch into the loop body

Iterative Statements: Examples

C-based languages

```
for ([expr_1] ; [expr_2] ; [expr_3]) statement
```

The expressions can be whole statements, or even statement sequences, with the statements separated by commas

- The value of a multiple-statement expression is the value of the last statement in the expression
- If the second expression is absent, it is an infinite loop

Design choices:

There is no explicit loop variable

Everything can be changed in the loop

The first expression is evaluated once, but the other two are evaluated with each iteration

Iterative Statements: Examples

C++ differs from C in two ways:

The control expression can also be Boolean

The initial expression can include variable definitions (scope is from the definition to the end of the loop body)

Java and C#

– Differs from C++ in that the control expression must be Boolean

Iterative Statements: Examples

Python

```
for loop_variable in object:
   loop body
[else:
   else clause]
```

– The object is often a range, which is either a list of values in brackets ([2, 4, 6]), or a call to the range function (range(5), which returns 0, 1, 2, 3, 4

– The loop variable takes on the values specified in the given range, one for each iteration

– The else clause, which is optional, is executed if the loop terminates normally

Statements: Logically-Controlled Loops

Repetition control is based on a Boolean expression

Design issues:

- Pretest or posttest?
- Should the logically controlled loop be a special case of the counting loop statement or a separate statement?

Iterative Statements: Logically-Controlled Loops: Examples

C and C++ have both pretest and posttest forms, in which the control expression can be arithmetic:

```
while (ctrl_expr)           do
   loop body                   loop body
                            while (ctrl_expr)
```

Java is like C and C++, except the control expression must be Boolean (and the body can only be entered at the beginning -- Java has no **goto**

Iterative Statements: Logically-Controlled Loops: Examples

Ada has a pretest version, but no posttest

FORTRAN 95 has neither

Perl and Ruby have two pretest logical loops, `while` and `until`. Perl also has two posttest loops

Iterative Statements: User-Located Loop Control Mechanisms

- Sometimes it is convenient for the programmers to decide a location for loop control (other than top or bottom of the loop)
- Simple design for single loops (e.g., `break`)
- Design issues for nested loops
  - Should the conditional be part of the exit?
  - Should control be transferable out of more than one loop?

Iterative Statements: User-Located Loop Control Mechanisms `break` and `continue`

- C , C++, Python, Ruby, and C# have unconditional unlabeled exits (**`break`**)
- Java and Perl have unconditional labeled exits (**`break`** in Java, **`last`** in Perl)
- C, C++, and Python have an unlabeled control statement, **`continue`**, that skips the remainder of the current iteration, but does not exit the loop
- Java and Perl have labeled versions of **`continue`**

Iterative Statements: Iteration Based on Data Structures

- Number of elements of in a data structure control loop iteration
- Control mechanism is a call to an *iterator* function that returns the next element in some chosen order, if there is one; else loop is terminate
- C's **`for`** can be used to build a user-defined iterator:

```
for (p=root; p==NULL; traverse(p)){
}
```

Iterative Statements: Iteration Based on Data Structures (continued)

PHP

`current` points at one element of the array

`next` moves `current` to the next element

`reset` moves `current` to the first element

Java

For any collection that implements the `Iterator` interface

`next` moves the pointer into the collection

`hasNext` is a predicate

`remove` deletes an element

Perl has a built-in iterator for arrays and hashes, **`foreach`**

Iterative Statements: Iteration Based on Data Structures (continued)

Java 5.0 (uses `for`, although it is called `foreach`)

- For arrays and any other class that implements `Iterable` interface, e.g., `ArrayList`

```
for (String myElement : myList) { … }
```

C#'s **`foreach`** statement iterates on the elements of arrays and other collections:

```
Strings[] = strList = {"Bob", "Carol",
"Ted"}; foreach (Strings name in strList)
    Console.WriteLine ("Name: {0}", name);
```

The notation `{0}` indicates the position in the string to be displayed

Iterative Statements: Iteration Based on Data Structures (continued)

Lua

- Lua has two forms of its iterative statement, one like Fortran's `Do`, and a more general form:

```
for variable_1 [, variable_2] in iterator (table) do
    ...
  end
```

- The most commonly used iterators are `pairs` and `ipairs`

Unconditional Branching

- Transfers execution control to a specified place in the program
- Represented one of the most heated debates in 1960's and 1970's
- Major concern: Readability
- Some languages do not support `goto` statement (e.g., Java)
- C# offers `goto` statement (can be used in `switch` statements)
- Loop exit statements are restricted and somewhat camouflaged `goto`'s

Guarded Commands

- Designed by Dijkstra
- Purpose: to support a new programming methodology that supported verification (correctness) during development
- Basis for two linguistic mechanisms for concurrent programming (in CSP and Ada)
- Basic Idea: if the order of evaluation is not important, the program should not specify one

Selection Guarded Command

Form

```
if <Boolean exp> -> <statement>
[] <Boolean exp> -> <statement>
 ...
[] <Boolean exp> -> <statement>
fi
```

Semantics: when construct is reached,

- Evaluate all Boolean expressions
- If more than one are true, choose one non-deterministically
- If none are true, it is a runtime error

Loop Guarded Command

Form

```
do  <Boolean> -> <statement>
[]  <Boolean> -> <statement>
...
[]  <Boolean> -> <statement>
od
```

Semantics: for each iteration

– Evaluate all Boolean expressions

– If more than one are true, choose one non-deterministically; then start loop again

– If none are true, exit loop

Guarded Commands: Rationale

- Connection between control statements and program verification is intimate
- Verification is impossible with `goto` statements
- Verification is possible with only selection and logical pretest loops
- Verification is relatively simple with only guarded commands

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

Conclusion

Variety of statement-level structures

Choice of control statements beyond selection and logical pretest loops is a trade-off between language size and writability

Functional and logic programming languages are quite different control structures

Unit-3

Subprograms and Blocks Abstract Data Types

CONCEPTS

Introduction
Fundamentals of Subprograms Design
Issues for Subprograms Local Referencing
Environments Parameter-Passing Methods
Parameters That Are Subprograms
Overloaded Subprograms
Generic Subprograms Design
Issues for Functions
User-Defined Overloaded Operators
Coroutines
Abstract Data types

Abstract Data types

- An *abstraction* is a view or representation of an entity that includes only the most significant attributes.
- The concept of *abstraction* is fundamental in programming (and computer science).
- Nearly all programming languages support *process abstraction* with subprograms.
- Nearly all programming languages designed since 1980 support *data abstraction*.

Introduction to Data Abstraction

- An *abstract data type* is a user-defined data type that satisfies the following two conditions:
- –The representation of, and operations on, objects of the type are defined in a single syntactic unit.
- –The representation of objects of the type is hidden from the program units that use these objects, so the only operations possible are those provided in the type's definition.

Encapsulation

Original motivation :

Large programs have two special needs:

Some means of organization, other than simply division into subprograms.

Some means of partial compilation (compilation units that are smaller than the whole program).

Obvious solution : a grouping of subprograms that are logically related into a unit that can be separately compiled. These are called encapsulations.

Examples ofEncapsulation Mechanisms

Nested subprograms in some ALGOL-like languages (e.g., Pascal).

FORTRAN 77 and C - Files containing one or more subprograms can be independently compiled.

FORTRAN 90, C++, Ada (and other contemporary languages) - separately compilable modules.

Language Requirements for Data Abstraction

- A syntactic unit in which to encapsulate the type definition.
  - A method of making type names and subprogram headers visible to clients, while hiding actual definitions.
  - Some primitive operations must be built into the language processor (usually just assignment and comparisons for equality and inequality).
    - Some operations are commonly needed, but must be defined by the type designer.

Language Design Issues

- Encapsulate a single type, or something more?
- What types can be abstract?
- Can abstract types be parameterized?
- What access controls are provided?

Language Examples

1. Simula 67

Provided encapsulation, but no information Hiding.

2. Ada

The encapsulation construct is the package

Packages usually have two parts:

Specification package (the interface)

Body package (implementation of the entities named in the specification.

Evaluation of Ada Abstract Data Types

- Lack of restriction to pointers is better -
- Cost is recompilation of clients when the
- representation is changed.
- Cannot import specific entities from other Packages.

Parameterized Abstract Data Types

1. Ada Generic Packages

Make the stack type more flexible by making the element type and the size of the stack generic.

---> SHOW GENERIC_STACK package and two instantiations .

Introduction

Two fundamental abstraction facilities

– Process abstraction

Emphasized from early days

– Data abstraction

Emphasized in the1980s