PRIMITIVE DATATYPES

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

The Integer Data Type

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

The Floating Point Data Type

Model real numbers, but only as approximations

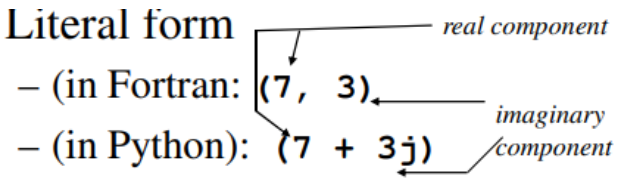
Languages for scientific use support at least two floating-point types (e.g., float and double; sometimes more

- Usually exactly like the hardware, but not always
- IEEE Floating-Point Standard 754

Complex Data Type

- 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



The Decimal Data Type

- 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

The Boolean DataType

- 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

The Character Data Type

• 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

1. C and C++

– Not primitive

– Use char arrays and a library of functions that provide operations

2. SNOBOL4 (a string manipulation language)

– Primitive

– Many operations, including elaborate pattern Matching

3. Fortran and Python

– Primitive type with assignment and several operations

4. Java

– Primitive via the String class

5. 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?

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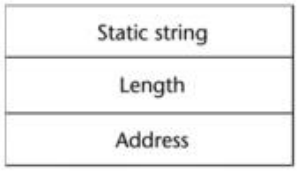
Character String Implementation

• Static length: compile-time descriptor

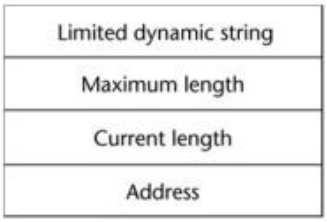
• Limited dynamic length: may need a runtime descriptor for length (but not in C and C++)

• Dynamic length: need run-time descriptor; allocation/deallocation is the biggest Implementation problem

Compile- and Run-Time Descriptors



Compile-time descriptor for static strings



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?

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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 a homogeneous aggregate of 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?
- Are ragged or rectangular multidimensional arrays allowed, or both?
- 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 and 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 runtime)

– Advantage: efficiency (no dynamic allocation)

• Fixed stack-dynamic: subscript ranges are statically bound, but the allocation is done at declaration time

– Advantage: space efficiency

• 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)

• 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)

- 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 heapdynamic 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

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

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

• Python

vector = [2, 4, 6, 8, 10, 12, 14, 16]

mat = [[1, 2, 3], [4, 5, 6], [7, 8, 9]]

– vector (3:6) is a three-element array

– mat[0][0:2] is the first and second element of the first row of mat

• Ruby supports slices with the slice method

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

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])

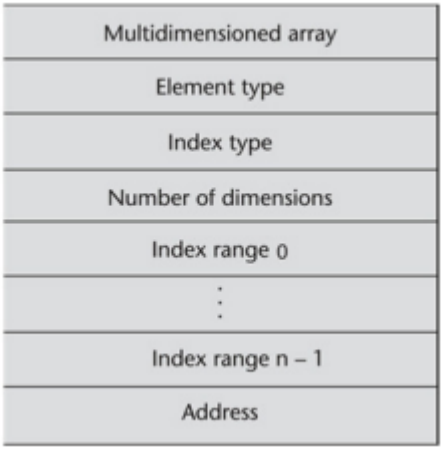
+ ((k-lower_bound) * element_size)

Accessing Multi-dimensioned Arrays

• Two common ways:

– Row major order (by rows) – used in most languages

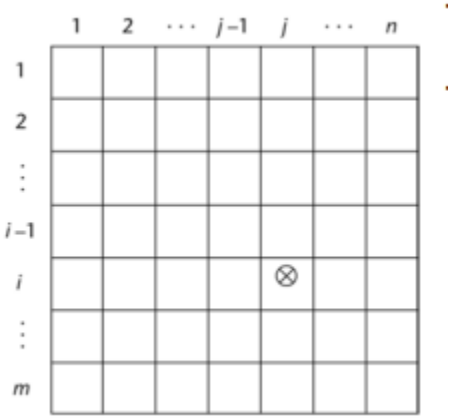
– Column major order (by columns) – used in Fortran – A compile-time descriptor for a Multidimensional array



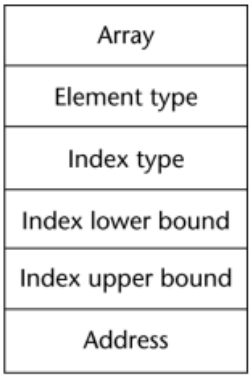
Locating an Element in a Multidimensioned Array

• General format

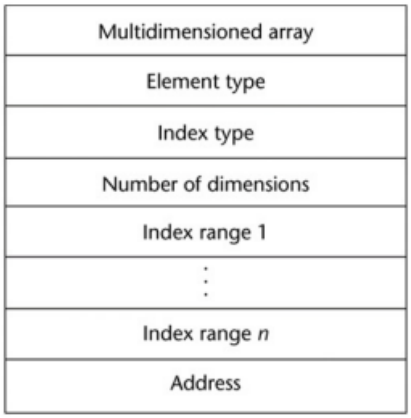
– Location (a[I,j]) = address of a [row_lb,col_lb] + (((I - row_lb) * n) + (j - col_lb)) * element_size



Compile-Time Descriptors



Single-dimensioned array



Multidimensional 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 %; 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"};