Data Structures

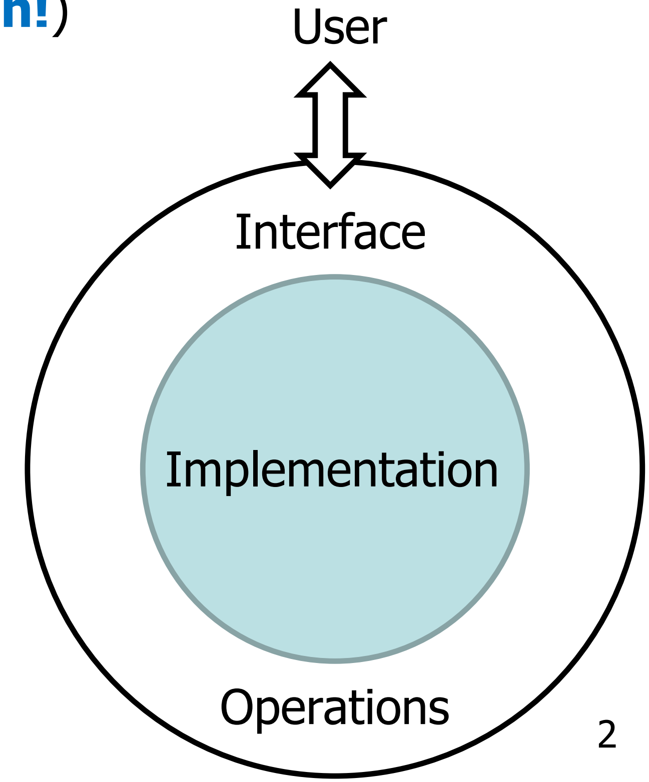
2. Arrays ADT and C++ Implementation

Abstract Data Types (1)

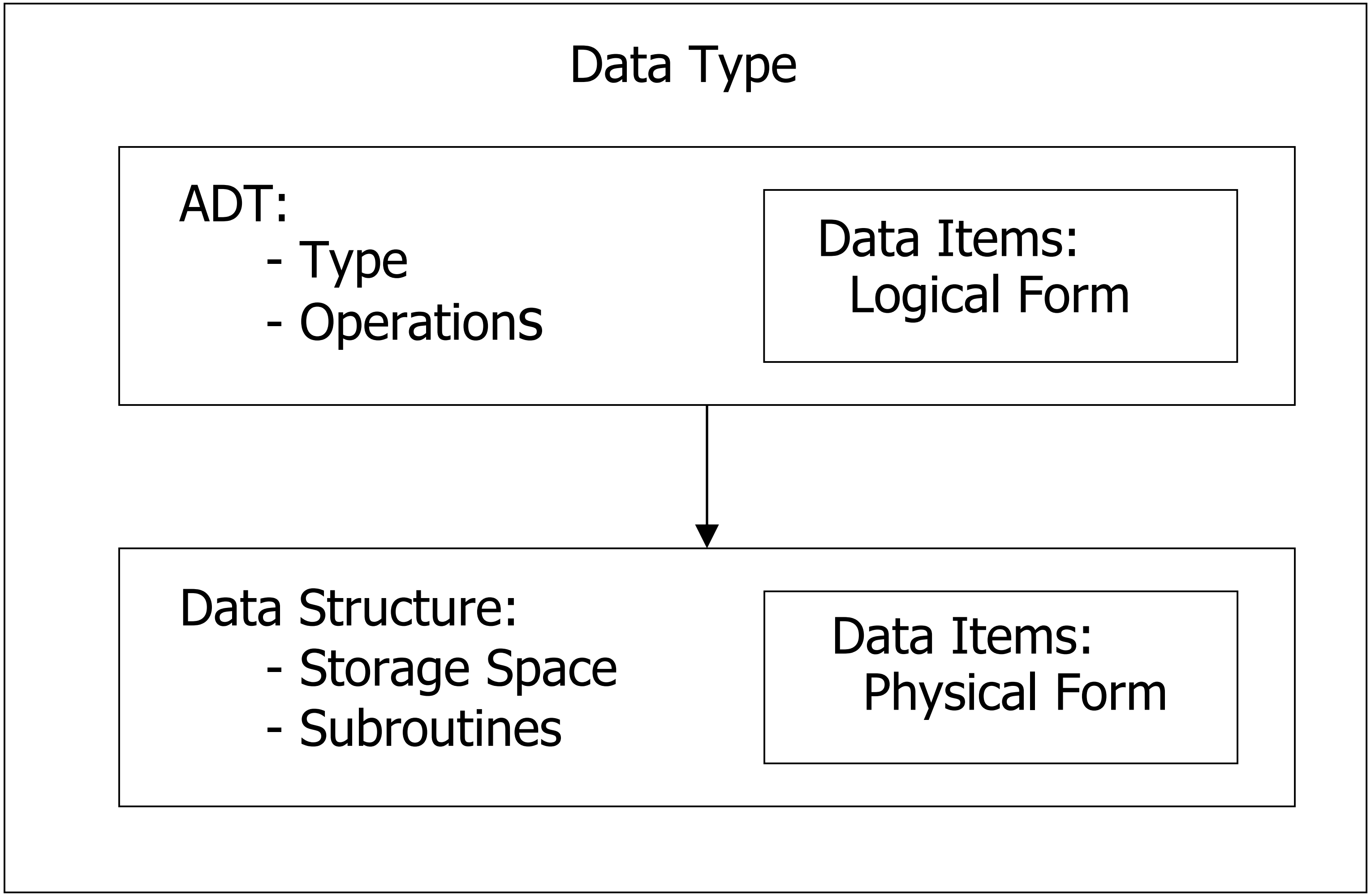
- A definition of data type solely in terms of
  - Set of related data items (or values)
  - Set of operations on the data

- Separation of logical properties from the implementation details
  - Hide implementation details (**Encapsulation!**)

- What not how is the focus



ADT vs. Data Structures



Data Type

ADT:
- Type
- Operations

Data Items:
Logical Form

Data Structure:
- Storage Space
- Subroutines

Data Items:
Physical Form

Example: Airplane Flight Reservation (1)

- Consider example of an airplane flight with 10 seats to be assigned

- Operations
  - List available seats
  - Reserve a seat

- Implementation: How to store, access data?
  - 10 individual variables

Implementation: 10 Individual Variables

List available seats:

```
1. if seat1 == ‘ ’;
       display 1
2. if seat2 == ‘ ’;
        display 2
.
.
.

10. if seat10 == ‘ ’;
        display 10
```

Reserve a seat:

```
1. Set DONE to false
2. if seat1 ==‘ ’;
   print “do you want seat #1??”
   Get answer
   if answer==‘Y’;
       set seat1 to ‘X’
       set Done to True
3. if seat2 ==‘ ’ and Done == false;
   print “do you want seat #2??”
   Get answer
   if answer==‘Y’;
       set seat2 to ‘X’
       set Done to True
.
.
.
```

Example: Airplane Flight Reservation (2)

- Consider example of an airplane flight with 10 seats to be assigned

- Operations
  - List available seats
  - Reserve a seat

- Implementation: How to store, access data?
  - 10 individual variables
  - An array of variables

Implementation: An array of variables

List available seats:

```
for number ranging from 0 to max_seats-1, do:
       if seat[number] == ‘ ’;
              Display number
```

Reserve a seat:

```
Reading number of seat to be reserved
if seat[number] is equal to ‘ ’;
       set seat[number] to ‘X’
else
       Display a message that the seat having this number is
       occupied
```

Example: Airplane Flight Reservation (2)

- This simple example illustrate the concept of an Abstract Data Type

- ADT consists of
  - Collection of data items
  - Basic operations that must be performed on them

- In the example, a collection of data is a list of seats

- Basic operations are
  - List available seats
  - Reserve a seat

Arrays

- An array is defined as
  - Ordered collection of a fixed number of elements
  - All elements are of the same data type

- Basic operations
  - Direct access to each element in the array
  - Values can be retrieved or stored in each element

Properties of an Array

- **Ordered**
  - Every element has a well-defined position
  - First element, second element, etc.
- **Fixed size or capacity**
  - Total number of elements are fixed
- **Homogeneous**
  - Elements must be of the same data type (and size)
  - Use arrays only for homogeneous data sets
- **Direct access**
  - Elements are accessed directly by their position
  - Time to access each element is same
  - Different to sequential access where an element is only accessed after the preceding elements

C/C++ Implementation of an Array ADT

```
dataType arrayName[intExp];
```

As an ADT	In C/C++
Ordered	Index: `0,1,2, … SIZE-1`
Fixed Size	`intExp` is constant
Homogeneous	`dataType` is the type of all elements
Direct Access	Array subscripting operator [ ]

Recap: Declaring Arrays in C/C++

```
dataType arrayName[intExp];
```

- `datatype` – Any data type, e.g., integer, character, etc.
- `arrayName` – Name of array using any valid identifier
- `intExp` – Constant expression that evaluates to a positive integer

Why constant?

- Example:
  - `const int SIZE = 10;`
  - `int list[SIZE];`

- Compiler reserves a block of consecutive memory locations enough to hold `SIZE` values of type `int`

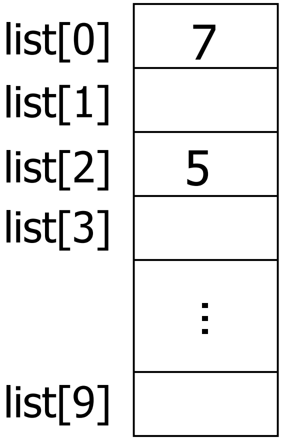
Recap: Accessing Arrays in C/C++

```
arrayName[indexExp];
```

- `indexExp` – called index, is any expression that evaluates to a positive integer

- In C/C++
  - Array index starts at 0
  - Elements of array are indexed `0, 1, 2, …, SIZE-1`
  - `[ ]` is called array subscripting operator

- Example
  - `int value = list[2];`
  - `list[0] = value + 2;`



list[0]	7
list[1]	
list[2]	5
list[3]	
	⋮
list[9]	

Array Initialization in C/C++ (1)

```
dataType arrayName[intExp]= {list of values}
```

- In C/C++, arrays can be initialized at declaration
  - `intExp` is optional: Not necessary to specify the size

- Example: Numeric arrays
  - `double score[ ] = {0.11, 0.13, 0.16, 0.18, 0.21}`

	0	1	2	3	4
score	0.11	0.13	0.16	0.18	0.21

- Example: Character arrays
  - `char vowel [5] = { ‘A’, ‘E’, ‘I’, ‘O’, ‘U’ }`

	0	1	2	3	4
vowel	A	E	I	O	U

Array Initialization in C/C++ (2)

- Fewer values are specified than the declared size of an array
  - Numeric arrays: Remaining elements are assigned zero
  - Character arrays: Remaining elements contains null character '\0'
    - ➢ ASCII code of '\0' is zero
- Example
  - `double score[5] = {0.11, 0.13, 0.16}`

	0	1	2	3	4
score	0.11	0.13	0.16	0	0

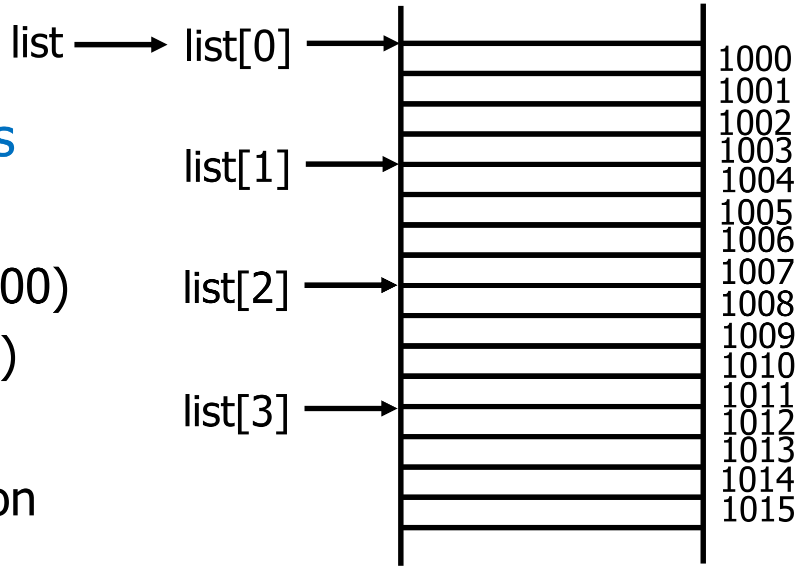
  - `char name[6] = {‘J’, ‘O’, ‘H’, ‘N’}`

	0	1	2	3	4	5
name	J	O	H	N	\0	\0

- If more values are specified than declared size of an array
  - Error is occurred: Handling depends on compiler

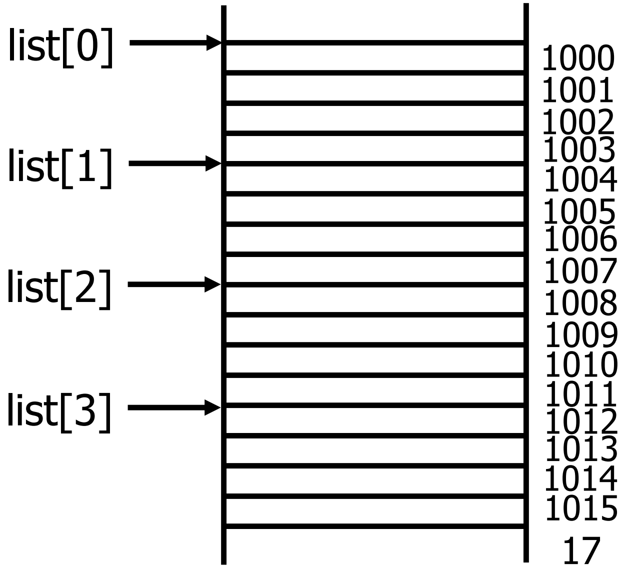
Array Addressing (1)

- Consider an array declaration: `int list [4] = { 1, 2, 4, 5}`
  - Compiler allocates a block of four memory spaces
  - Each memory space is large enough to store an `int` value
  - Four memory spaces are contiguous
- Base address
  - Address of the first byte (or word) in the contiguous block of memory
  - Address of the memory location of the first array element
    - Address of element `list[0]`
- Memory address associated with `arrayName` stores the base address
- Example
  - `cout << list << endl;` (Print 1000)
  - `cout << *list << endl;` (Print 1)
- `*` is dereferencing operator
  - Returns content of a memory location



Array Addressing (2)

- Consider a statement: `cout << list[3];`
  - Requires array reference `list[3]` be translated into memory address
  - Offset: Determines the address of a particular element w.r.t. base address
- Translation
  - Base address + offset = 1000 + 3 x `sizeof(int)` = 1012
  - Content of address 1012 are retrieved & displayed
- An address translation is carried out each time an array element is accessed
- What will be printed and why?
  - `cout << *(list+3) << endl;`



Questions

- Why does an array index start at zero?

- Why are arrays not passed by value?

Multidimensional Arrays

- Most languages support arrays with more than one dimension
  - High dimensions capture characteristics/correlations associated with data
- Example: A table of test scores for different students on several tests
  - 2D array is suitable for storage and processing of data

	Test 1	Test 2	Test 3	Test 4
Student 1	99.0	93.5	89.0	91.0
Student 2	66.0	68.0	84.5	82.0
Student 3	88.5	78.5	70.0	65.0
:	:	:	:	:
:	:	:	:	:
Student N	100.0	99.5	100.0	99.0

Two Dimensional Arrays – Declaration

```
dataType arrayName[intExp1][intExp2];
```

- `intExp1` – constant expression specifying number of rows
- `intExp2` – constant expression specifying number of columns

- Example:
  - `const int NUM_ROW = 2, NUM_COLUMN = 4;`
  - `double scoreTable [NUM_ROW][NUM_COLUMN];`

- Initialization:

  -
    ```
    double scoreTable [ ][4] = { {0.5, 0.6, 0.3},
                                  {0.6, 0.3, 0.8}};
    ```
  - List the initial values in braces, row by row
  - May use internal braces for each row to improve readability

Two Dimensional Arrays – Processing

```
arrayName[indexExp1][indexExp2];
```

- `indexExp1` – row index
- `indexExp2` – column index

- Rows and columns are numbered from 0
- Use nested loops to vary two indices
  - Row-wise or column-wise manner

- Example
  - `double value = score[2][1];`
  - `score[0][3] = value + 2.0;`

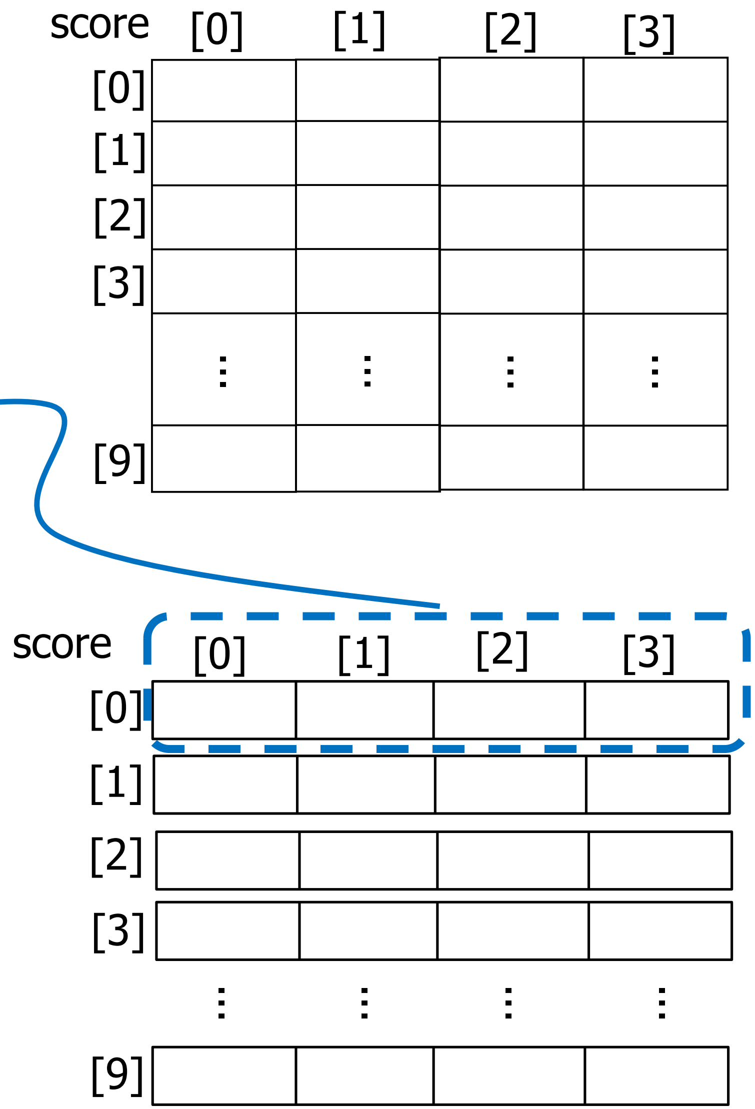
score	[0]	[1]	[2]	[3]
[0]				2.7
[1]				
[2]		0.7		
[3]				
	⋮	⋮	⋮	⋮
[9]				

Array of Arrays (1)

- Consider the declaration
  - `double score[10][4];`

- Another way of declaration
  - One-dimensional (1D) array of rows

```
typedef double RowOfTable[4];
RowOfTable score[10];
```



- In detail
  - Declare score as 1D array containing 10 elements
  - Each of 10 elements is 1D array of 4 real numbers (i.e., double)

Array of Arrays (2)

- `Score[i]`
  - Indicates ith row of the table

- `Score[i][j]`
  - Can be thought of as `(score[i])[j]`
  - Indicates jth element of `score[i]`

Generalization:

An n-dimensional array can be viewed (recursively) as a 1D array whose elements are (n-1)-dimensional arrays

Array of Arrays – Address Translation

- How to access the value of `score[5][3]`?

- Suppose base address of score is 0x12348

- Address of 5th element of score array, i.e., `score[5]`
  - 0x12348 + 5 x `sizeof(RowOfTable)` = 0x12348 + 5 x (4 x 8)
    = 0x12488

- Address of `score[5][3]`
  - Address of `score[5] + 3 x sizeof(double)` = 0x12488 + 3 x 8
    = 0x124a0

```
typedef double RowOfTable[4];
RowOfTable score[10]
```

Higher Dimensional Arrays

- Example: Store and process a table of test scores
  - For several different students
  - On several different tests
  - Belonging to different semesters

```
const int SEMS = 10, STUDENTS = 30, TESTS = 4;
typedef double ThreeDimArray[SEMS][STUDENTS][TESTS];
ThreeDimArray gradeBook;
```

- What is represented by `gradebook[4][2][3]`?
  - Score of 3rd student belonging to 5th semester on 4th test

- All indices start from zero

Implementing Multidimensional Arrays

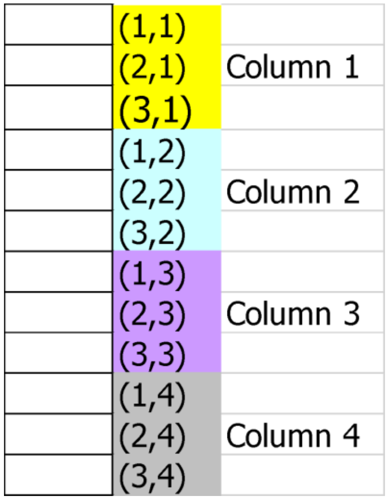
- More complicated than one dimensional arrays
- Memory is organized as a sequence of memory locations
  - One-dimensional (1D) organization
- How to use a 1D organization to store multidimensional data?
- Example:

$$\begin{pmatrix} A & B & C & D \\ E & F & G & H \\ I & J & K & L \end{pmatrix}$$

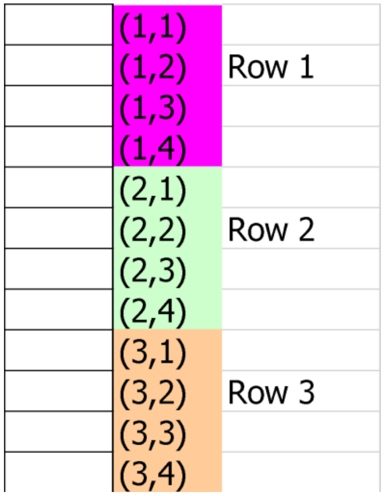
  - A character requires single byte
  - Compiler request to reserve 12 consecutive bytes
  - Two way to store consecutively, i.e., row-wise and column-wise

Two-dimensional Arrays in Memory

- Two ways to be represented in memory
  - Column majored
    - ➢ Column by column
  - Row majored
    - ➢ Row by row
  - Representation depends upon the programming language



	(1,1)	
	(2,1)	Column 1
	(3,1)	
	(1,2)	
	(2,2)	Column 2
	(3,2)	
	(1,3)	
	(2,3)	Column 3
	(3,3)	
	(1,4)	
	(2,4)	Column 4
	(3,4)	



	(1,1)	
	(1,2)	Row 1
	(1,3)	
	(1,4)	
	(2,1)	
	(2,2)	Row 2
	(2,3)	
	(2,4)	
	(3,1)	
	(3,2)	Row 3
	(3,3)	
	(3,4)	

Any Question So Far?