



COMP 2012H Honors Object-Oriented Programming and Data Structures

Topic 5: Array – a Collection of Homogeneous Objects

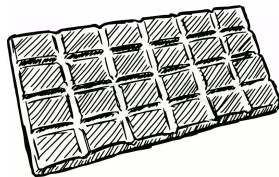
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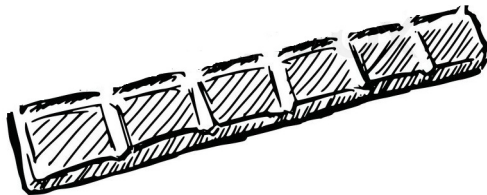
What is an Array?

- **Array** is a collection of **homogeneous** objects: objects of the **same** type. e.g. a collection of int, char, double, ..., or user-defined types.
- **Exception:** The array elements cannot be reference variables.



Part I

1-Dimensional Array



C++ 1-Dimensional Array

Syntax: Definition of a 1D Array

<data-type> <array-name> [<size>] ;

- <size> should be a **positive constant**. It can be a constant expression too.

Examples

```
int number[10000]; // an array of 10,000 uninitialized integers

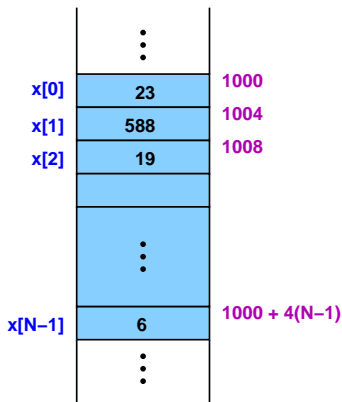
const int NUM_STUDENTS = 335;
char gender[NUM_STUDENTS];      // an array of 335 char
float score[NUM_STUDENTS + 1]; // an extra element to hold the mean

int n = 3;
double x[n];                    // compilation error on VC++: size is NOT a constant

int value[-4];                 // compilation error: array size cannot be -ve
```

Subscripting: Access to Each Array Element

(if x is an int array, $\text{sizeof}(\text{int}) = 4$)



- A 1D **array** is an ordered list of elements.
- **Successive** elements are stored in **contiguous memory**.
- To access an element, use the **subscript operator** `[]` with an **array index**.
- For an array of size N , the indices run from $0, 1, 2, \dots, N - 1$.
- Each array element is treated like a regular variable:
 - ▶ you may assign a value to it
 - ▶ you may assign its value to another variable
 - ▶ you may pass it by **value** or **reference** to a function

Array and Control

- **Array** works particularly well with loops: e.g. use a **for**-loop to access and manipulate each array element in turn.
- This is not a coincidence, but part of the C++ **language design**.

Examples

```
int y;           // A regular int variable
int x[3];        // An array of 3 int numbers

x[0] = 34;       // Array indices start from zero in C++
x[1] = 289;
x[2] = 75;       // Index of the last element is 2 NOT 3!

y = x[2];        // Now both y and x[2] are 75
max(x[2], x[0]); // Pass array elements by value
swap(x[1], x[0]); // Pass array elements by reference

for (int j = 0; j < 3; j++)
    x[j] *= 3;    // Triple each element of an array
```

Example: Manipulate an Array of Scores using **for** Loop

```
#include <iostream>      /* array-mean.cpp */
using namespace std;

int main()
{
    const int NUM_STUDENTS = 5;
    float score[NUM_STUDENTS];
    float sum_score = 0; // Don't forget initializing the sum

    for (int j = 0; j < NUM_STUDENTS; ++j)
    {
        cin >> score[j];
        sum_score += score[j]; // Accumulate the scores
    }

    cout << "mean score = " << sum_score/NUM_STUDENTS << endl;
    return 0;
}
```

Example: Manipulate an Array of Scores using **for** Loop ..

```
#include <iostream>      /* array-max.cpp */
using namespace std;

int main()
{
    const int NUM_STUDENTS = 5;
    float score[NUM_STUDENTS];
    // Read in the first student's score. Assume #student >= 1
    cin >> score[0];
    float max_score = score[0]; // A good way to initialize max score

    for (int j = 1; j < NUM_STUDENTS; ++j)
    {
        cin >> score[j];
        if (max_score < score[j])
            max_score = score[j];
    }

    cout << "max score = " << max_score << endl;
    return 0;
}
```


Wrong Subscript: Common Reason for Segmentation Fault

- C++ compiler does not automatically check that an array index is **out of bound**.
- That is, for an array of size N , the compiler won't check if it is subscripted with an index between **0** and $N - 1$, neither at **compile-time** nor **run-time**.
- There is no compilation error for the following codes:

```
int x[10]; x[-2] = 5; x[100] = 9;
```

- When the codes are run, `x[-2] = 5;` will put the value 5 to the memory space which is 2×4 bytes (size of 2 int) **before** the array `x`. Similarly, `x[100] = 9;` will put the value 9 to the memory space which is 90×4 bytes **beyond** the array.
- This is a common cause of the **run-time error** called **segmentation fault** — your program trespasses into memory locations that do not belong to it.

Array Initialization

- Just like any **local** variable, when an array is defined, its elements are not initialized automatically.

Syntax: Define and Initialize a 1D Array Simultaneously

```
<data-type> <array-name> [<size>]  
= { <value0>, <value1>, ..., <value<size>-1> } ;
```

- If there are **fewer** values than the array size, the unspecified values will be **zeros**.
- It is a **compilation error** if there are **more** values than the array size.
- If you leave out the array size in the array initialization, the compiler will count the number of initializing values and uses that as the array size.
- Once defined, you **cannot** assign values to an array using the initialization syntax.

Example: Array Initialization

```
int a[5] = {1, 2, 3, 4, 5};  
/* Same as  
  
   int a[5];  
   a[0] = 1; a[1] = 2; a[2] = 3; a[3] = 4; a[4] = 5;  
*/  
  
int b[5] = {1, 2};    // => 1, 2, 0, 0, 0  
int c[5] = {};        // => 0, 0, 0, 0, 0  
int d[] = {1, 2, 3};  // Compiler determines the size=3 automatically  
int e[3];  
  
// Compilation error:  
//      can't assign values to an array using the { } syntax  
e = {5, 6, 7};  
  
// Compilation error: can't declare an array of references  
double x = 1.5, y = 2.5, z = 3.5;  
int& s[] = {x, y, z};
```

Common Mis-uses of an Array

While each array element can be treated as a simple variable, the whole array, as represented by the array identifier, cannot.

Examples: Correct and Incorrect Uses of Arrays

```
int x[] = {1, 2, 3, 4, 5 };
int y[] = {6, 7, 8, 9, 0 };
int z[5];

/* Incorrect way */
// Cannot assign to array elements using the initialization syntax
x = {5, 4, 3, 2, 1};

x = 8;          // x is not an integer! Its elements are.
x += 2;         // x is not an integer! Its elements are.
x = y;          // No assignment between 2 arrays
z = x + y;      // Cannot +, -, *, / on the array, but only its elements

/* Correct way; what does each for-statement do? */
for (int j = 0; j < 5; ++j) x[j] = 5 - j;
for (int j = 0; j < 5; ++j) x[j] = 8;
for (int j = 0; j < 5; ++j) x[j] += 2;
for (int j = 0; j < 5; ++j) x[j] = y[j];
for (int j = 0; j < 5; ++j) z[j] = x[j] + y[j];
```

Pass a 1D Array to a Function

Examples: Arrays as Function Arguments

```
/* function header */  
float mean_score(float score[], int size) { ... }  
float max_score(float score[], int size) { ... }  
  
/* inside the main() */  
float score[NUM_STUDENTS];  
mean_score(score, NUM_STUDENTS);  
max_score(score, NUM_STUDENTS);
```

- Since the **array identifier** alone does *not* tell us about its size, a function that operates on an array needs at least 2 input arguments:
 - ▶ the **array identifier**
 - ▶ the **array size** (of type **int**)

Example: Pass an Array to a Function I

```
#include <iostream>      /* array-mean-max-fcn.cpp */
using namespace std;

float mean_score(float score[], int size)
{
    float sum_score = 0.0; // Don't forget initializing the sum to 0
    for (int j = 0; j < size; j++)
        sum_score += score[j]; // Accumulate the scores
    return sum_score/size;
}

float max_score(float score[], int size)
{
    // Initialize the max score to that of the first student
    float max_score = score[0];
    for (int j = 1; j < size; j++)
        if (max_score < score[j])
            max_score = score[j];
    return max_score;
}
```

Example: Pass an Array to a Function II

```
int main()
{
    const int NUM_STUDENTS = 5;
    float score[NUM_STUDENTS];

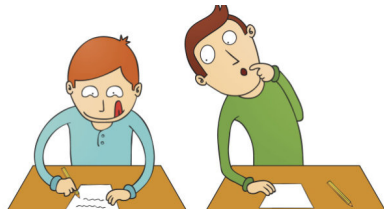
    for (int j = 0; j < NUM_STUDENTS; j++)
        if (!(cin >> score[j])) return -1;

    cout << "mean score = " << mean_score(score, NUM_STUDENTS) << endl;
    cout << "max score = " << max_score(score, NUM_STUDENTS) << endl;
    return 0;
}
```

Notice how we may check if the input operation is successful:

```
if(!(cin >> scores[j]))
```

It returns **true/false** if it **succeeds/fails**, respectively.



1D Array as a Function's Formal Parameter

- While a regular variable may be passed to a function by value or reference, an array variable is always **passed by value**.
- However, although the array variable is **passed by value**, its elements are *effectively* **passed by reference**!
- Any **change** to an array element inside the function will **persist** even after the function **returns**.
- Just like a regular variable, you pass an array to a function simply by its variable name. e.g.

```
max_score(score, NUM_STUDENTS);
```


Example: Modifying Array's Elements by a Function I

```
#include <iostream>      /* array-add-rotate.cpp */
using namespace std;

void array_add(int x[], int y[], int z[], int size)
{
    for (int j = 0; j < size; j++)
        z[j] = x[j] + y[j];
}

void circular_rotation(int x[], int size)
{
    int item_0 = x[0];    // Save the first element before rotation
    for (int j = 1; j < size; j++)
        x[j-1] = x[j];    // Rotate up
    x[size - 1] = item_0; // Fix the last element
}

void array_print(int x[], int size)
{
    for (int j = 0; j < size; j++)
        cout << x[j] << '\t';
    cout << endl;
}
```

Example: Modifying Array's Elements by a Function II

```
int main()
{
    int a[] = {1, 2, 3, 4};
    int b[] = {11, 12, 13, 14};
    int c[4];

    array_add(a, b, c, 4);
    array_print(c, 4);
    cout << endl;

    for (int k = 0; k < 4; k++)
    {
        circular_rotation(a, 4);
        array_print(a, 4);
    }

    return 0;
}
```



Constant Array

- Just like simple constants, an array of constants can be made using the keyword “**const**”.

```
const int x[] = { 1, 2, 3, 4 };
```

It defines 4 integer constants: $x[0]$, $x[1]$, $x[2]$, and $x[3]$ are all of the type **const int**.

- Like simple constants, a **constant array**
 - must be **initialized** when it is **defined**.
 - once defined, its elements **cannot** be modified.
- One main use of constant array is in the definition of the formal parameters of a function: to **disallow modification** of the **elements** of an array passed to a function, declare that array constant using **const**.
 - inside the function, the array is **read-only**.
 - however, the original array in the caller is still **writable**.

Example: Prevent Modification by Constant Array I

```
#include <iostream>          /* const-array-mean-max-fcn.cpp */
using namespace std;

float mean_score(const float score[], int size)
{
    float sum_score = 0.0;  // Don't forget initializing the sum to 0
    for (int j = 0; j < size; j++)
        sum_score += score[j]; // Accumulate the scores
    return sum_score/size;
}

float max_score(const float score[], int size)
{
    // Initialize the max score to that of the first student
    float max_score = score[0];
    for (int j = 1; j < size; j++)
        if (max_score < score[j])
            max_score = score[j];
    return max_score;
}
```

Example: Prevent Modification by Constant Array II

```
int main()
{
    const int NUM_STUDENTS = 5;
    float score[NUM_STUDENTS];

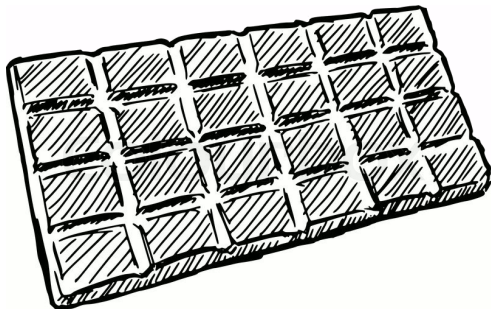
    for (int j = 0; j < NUM_STUDENTS; j++)
        if (!(cin >> score[j]))
            return -1;

    cout << "mean score = " << mean_score(score, NUM_STUDENTS) << endl;
    cout << "max score = " << max_score(score, NUM_STUDENTS) << endl;
    return 0;
}
```



Part II

Multi-dimensional Array



C++ 2-dimensional Array

Syntax: Definition of a 2D Array

<data-type> <array-name> [<size₁>] [<size₂>] ;

```
int a[2][3] = {1,2,3,4,5,6}; // sizeof(int) = 4
```

		COLUMN				
		0	1	2		
ROW	0	a[0][0]	a[0][1]	a[0][2]	a[0][0]	1000
	1	a[1][0]	a[1][1]	a[1][2]	a[0][1]	1004
					a[0][2]	1008
					a[1][0]	1012
					a[1][1]	1016
					a[1][2]	1020

Initialization of 2D Array

- A **2D array** can be initialized in 2 ways:
 - ▶ **row by row**, or
 - ▶ **like a 1D array** since the array cells are actually **stored linearly** in the memory.

Examples

```
/* Initialize row by row */
int point[5][2] = { // An int array with 5 rows and 2 columns
    {1, 1},
    {2, 4},
    {3, 9},
    {4, 16},
    {5, 25}
};

/*
 * Initialize using the fact that the cells of a 2D
 * array actually are stored linearly in the memory
 */
int point[5][2] = { 1,1, 2,4, 3,9, 4,16, 5,25 };
```


Example: Functions with 2D Array I

```
#include <iostream>      /* File: 2d-array-fcn.cpp */
#include <cmath>
using namespace std;

float euclidean_distance(float x1, float y1, float x2, float y2)
{
    float x_diff = x1 - x2, y_diff = y1 - y2;
    return sqrt(x_diff*x_diff + y_diff*y_diff);
}

void print_2d_array(const float a[][3], int num_rows, int num_columns)
{
    for (int i = 0; i < num_rows; i++)
    {
        for (int j = 0; j < num_columns; j++)
            cout << a[i][j] << '\t';

        cout << endl;
    }
}
```

Example: Functions with 2D Array II

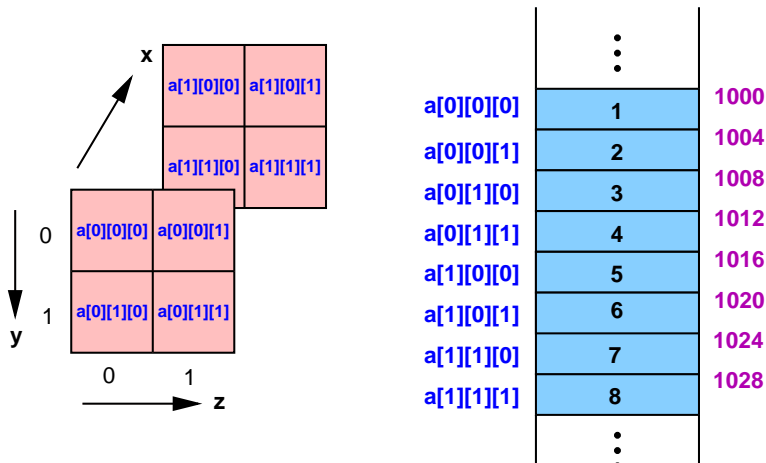
```
void compute_all_distances(  
    const float point[][2], float dist[][3], int num_points)  
{  
    for (int i = 0; i < num_points; i++)  
        for (int j = 0; j < num_points; j++)  
            dist[i][j] = euclidean_distance(point[i][0], point[i][1],  
                                              point[j][0], point[j][1]);  
}  
  
int main()  
{  
    float dist[3][3];    // Distances between any pairs of points  
    float point[3][2]    // (x, y) coordinates of 3 points  
        = { {1.0, 1.0} , {2.0, 2.0} , {4.0, 3.0} };  
  
    compute_all_distances(point, dist, 3);  
    print_2d_array(dist, 3, 3);  
    return 0;  
}
```

C++ N-dimensional Array

Syntax: Definition of an N-dimensional Array

<data-type> <array-name> [<size₁>] [<size₂>] \cdots [<size_N>] ;

```
int a[2][2][2] = {1,2,3,4,5,6,7,8}; // sizeof(int) = 4
```

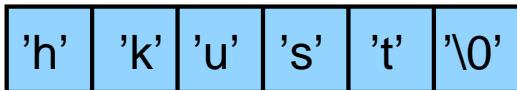


Remarks on Multi-dimensional Array

- Although conceptually a 2D array is like a matrix, and a 3D array is like a cube, the elements of a multi-dimensional array are **stored linearly** in the memory (just like a 1D array).
- In C++, the elements of a multi-dimensional array are stored in **row-major order**: row by row.
- There are programming languages (e.g. FORTRAN) that store multi-dimensional array elements in **column-major order**: column by column.
- In row-major order, the **last** dimension index runs **fastest**, while the **first** dimension index runs **slowest**.
- If a multi-dimensional array is used in a C++ function, **all dimensions other than the first dimension** must be specified in its declaration in the function header.

Part III

C String: Special 1D Character Array



C String

- In general, one cannot deal with the **whole** array at once, but has to deal with **each** array element, one at a time because a sequence of, e.g., integers, do not represent a new object.
- A **char array** is different: a **sequence** of chars may be interpreted as a word or sentence or paragraph or even a novel!
- C++ follows C's trick of representing a character string by a **1D character array** with the **end-marker** `'\0'`.
- Just add the **null character** `'\0'` (ASCII code = 0) **after** the **last** character of the string you need.

'h'	'k'	'u'	's'	't'	'\0'
-----	-----	-----	-----	-----	------

C String ..

- For a **string** of length N , add `'\0'` as the $(N + 1)$ th element of its **char array**.
- Now if everyone writes functions of **char arrays** that represents **strings** with the above understanding, then one **doesn't** need to pass the size of such **char arrays** to their functions!
- C++ allows another notation using the **double quotes**. e.g.,

`"hkust" = 'h' 'k' 'u' 's' 't' '\0'`

Example: C String

```
#include <iostream>      /* File: c-string.cpp */
using namespace std;

int main()
{
    char s1[6] = {'h', 'k', 'u', 's', 't', 'z'};

    // At this point, s1 is still a simple char array
    for (int j = 0; j < 5; j++)
        cout << s1[j];
    cout << endl;

    s1[5] = '\0';        // Now, s1 is a C string
    cout << s1 << endl;

    // Another notation for initializing literal constant strings
    char s2[20] = {'h', 'k', 'u', 's', 't', '\0'};
    cout << "s2 = " << s2 << endl;
    char s3[20] = "hkust"; cout << "s3 = " << s3 << endl;
    return 0;
}
```


Example: Some C String Functions I

```
#include <iostream>      /* File: c-string-fcn.cpp */
using namespace std;
const char NULL_CHAR = '\0';

int str_len(const char s[])
{
    int j;
    for (j = 0; s[j] != NULL_CHAR; j++)
        ;
    return j;
}

int str_concatenate(const char s1[], const char s2[], char s[])
{
    int j;
    for (j = 0; s1[j] != NULL_CHAR; j++)
        s[j] = s1[j];    // Copy s1 to s

    for (int k = 0 ; s2[k] != NULL_CHAR; k++, j++)
        s[j] = s2[k];    // Copy s2 after s1

    s[j] = NULL_CHAR;    // Make s a C String
    return j;
}
```

Example: Some C String Functions II

```
int main()
{
    char a[20] = "Albert";
    char b[20] = "Einstein";
    char c[20];
    int length;

    cout << "length of string a = " << str_len(a) << endl;
    cout << "length of string b = " << str_len(b) << endl;

    length = str_concatenate(a, b, c);
    cout << "After concatenation: "
         << c << " of length " << length << endl;

    return 0;
} // Read http://www.cplusplus.com/reference/cstring/
   // for more C string library functions.
```

Example: Functions with 2D Character Array

```
#include <iostream>      /* File: str-array.cpp */
using namespace std;

void print_strings(const char s[][16], int num_of_strings)
{
    for (int j = 0; j < num_of_strings; j++)
        cout << s[j] << " ";
    cout << endl;
}

int main()
{
    // 5 C-strings, each having a max. length of 15 char
    const char word[5][16] = {
        "hong kong",
        "university",
        "of",
        "science",
        "technology"
    };

    print_strings(word, 5);
    return 0;
}
```

Reading C Strings with `cin`

- `cin` will skip all **white spaces** before reading data of the required type until it sees the next white space.
- **White spaces** are any sequence of ' ', '\t' and '\n'.
- For `char x; cin >> x;`, if the input is " hkust ", `cin` will skip all the **leading white spaces**, and gives 'h' to x.
- The same is true for reading a C string.
- For `char x[20]; cin >> x;`, if the input is " hkust ", `cin` will skip all the **leading white spaces**, and gives "hkust" to x.
- Thus, `cin >>` is not good at reading **multiple** words or even a paragraph including possibly the newline. Instead, use:

`cin.getline(char s[], int max-num-char, char terminator);`
- `cin.getline()` will stop when **either** (*max-num-char* - 1) characters are read, OR, the terminating character *terminator* is seen. The terminating character is removed from the input stream but is **not** read into the string.
- The C-string terminating null character is automatically inserted at the end of the read string.

Example: `cin.getline()` from "[hacker.txt](#)"

```
#include <iostream>      /* File: read-str.cpp */
using namespace std;

int main()
{
    const int MAX_LINE_LEN = 255;
    char s[MAX_LINE_LEN+1];

    // Read until the newline character (default)
    cin.getline(s, MAX_LINE_LEN+1, '\n');
    cout << s << endl;

    // Read until the character 'W'
    cin.clear(); // Clear the failbit if max #chars are read
    cin.getline(s, sizeof(s), 'W');
    cout << s << endl;

    return 0;
}
```

That's all!

Any questions?

