IM 1003: Programming Design

Arrays

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Variables and arrays

- We know each variable must have a **type**.
- So far all variables we declared are of basic data types.
- There are other types:
  - Arrays.
  - Pointers.
  - Self-defined data types (e.g., classes).
- Today we introduce **arrays**.
  - A collection of variables of the same type.
  - An array variable is of an **array type**.

Outline

- **More about variables**
  - Constant variables
  - Casting among basic data types
- Arrays
- C strings: character arrays

Constant variables

- Sometimes we want to use a variable to store a particular value.
  - In a program doing calculations regarding circles, the value of π may be used **repeatedly**.
  - We do not want to write many `3.14` throughout the program! Why?
  - We may declare `pi = 3.14` once and then use `pi` repeatedly.
- In this case, this variable is actually a **symbolic constant**.
  - We want to prevent it from being **modified**.

Constant variables

- A **constant** is one kind of variables.
- To declare a constant, use the key word `const`:
  - `const int a = 100;`
  - All further assignment operations on a constant generate compilation errors.
  - That is why we must **initialize** a constant.
- It is suggested to use **capital characters** and **underlines** to name constants. This distinguishes them from usual variables.
  - `const double PI = 3.1416;`
  - `const int MAX_LEVEL = 5;`
  - Some people use lowercase characters and underlines.

Casting

- Variables are **containers**.
- Variables of different types are containers of different **sizes/shapes**.
  - **long** ≧ **int** ≧ **short**.
  - "Shapes" of **int** and **float** are different (though sizes are identical).
- A big container may store a small item. A big item must be "cut" to be stored in a small container.
  - So are variables of different types.

```
short s = 100;
int i = s; // 100
i = 100000;
s = i; // -31072
```

```
double d = 5; // d = 5.0
int s = 5.5; // s = 5
```

Casting

- Changing the type of a variable or literal is called **casting**.
- There are two kinds of casting:
  - **Implicit casting**: from a small type to a large type.
  - **Explicit casting**: from a large type to a small type.
- When implicit casting occurs, there is no value of precision loss.
  - The system does that automatically.
  - The value of that variable or literal does not change.
  - There is no need for a programmer to indicate how to implicitly cast one small type to a large type.
- To cast a large type to a small type, a programmer is responsible for indicating **how to do it** explicitly.

Explicit casting

- Suppose we want to store 5.6 to an integer:
  - `int a = 5.6;` is not good.
  - `int a = static_cast<int>(5.6);` is better.
- To cast basic data types, we use **`static_cast`**:

```
static_cast<type>(expression)
```

  - When a float or double is cast to an integer value (and there is no value loss), the fractional part is **truncated**.
- In the example above, both statements makes **`a`** equal 5.
  - Then why bothering?

Explicit casting

- Explicit casting is to indicate the **way** of casting we want.
  - For basic types, there is only one way to cast a large type to a small type.
  - For more complicated types, however, there may be **multiple**.
- There are four different explicit casting operators.
  - `static_cast`, `dynamic_cast`, `reindivter_cast`, and `const_cast`.
  - For basic data types, `static_cast` is enough.
- By explicitly indicating how to cast:
  - This is to make sure that, at the run time, the program runs as we expect.
  - This is also to notify other programmers (or the future ourselves).
- Explicit casting also allows for a temporary change of types (see below).

Good programming style

- There is an old way of explicit casting:

```
(type) expression
```

  - For example, `int a = (int) 5.6;` .
- Try to avoid it!
  - This operation includes all four possibilities, and we have no idea which one will be performed at the run time.
- If possible, try to modify your variable declaration to avoid casting.

Casting for division

- Let's try this program:
- The **division** operator returns an integer if both operands (numerator and denominator) are integers.
- How to get our desired results?
  - If allowed, we may change the data types of the operands.
  - If not allowed, we may cast the operands **temporarily**.

```
int d1 = 10;
int d2 = 3;
cout << d1 / d2 << "\n";

double d3 = 10;
int d4 = 3;
cout << d3 / d4 << "\n";

int d5 = 10;
double d6 = 3;
cout << d5 / d6 << "\n";
```

Casting for division

- Which one works?

```
int d1 = 10;
int d2 = 3;
cout << static_cast<double>(d1 / d2);
```

```
int d1 = 10;
int d2 = 3;
cout << static_cast<double>(d1) / d2;
```

- Casting can be a big issue when we work with nonbasic data types.
- At this moment, just be aware of fractional and integer values.

Outline

- More about variables
- **Arrays**
  - **Single-dimensional arrays**
  - Multi-dimensional arrays
- C strings: character arrays

Set of similar variables

- Suppose we want to write a program to store five students' scores.
- We may need to declare 5 variables.
  - `int score1, score2, score3, score4, score5;`
- What if we have 500 students? How to declare 500 variables?
- Even if we have only 5 variables with very similar names, we are unable to write a loop to output all of them.

```
for (int i = 0; i < 5; i++)
{
  cout << score1; // and then?
}
```

Why arrays?

- An array is a collection of variables with **the same type**.
- To declare five integer variables for scores, we may write:

```
int score[5];
```

  - These variables are declared with **the same array name** (`score`).
  - They are distinguished by their **indices**.

```
cout << score[2];
```

- An array is also a **type**: A nonbasic data type.
  - The type of `score` is "a length-5 integer array".

An array is a type

- Arrays are often used with loops.
  - Quite often the loop counter is used as the array index.

```
int score[5];
for (int i = 0; i < 5; i++)
  cin >> score[i];
for (int i = 0; i < 5; i++)
  cout << score[i] << " ";
```

- An array is also a (nonbasic) **type**.
  - The type of `score` is "a integer array" (of length 5).
  - What is this?

```
cout << score;
```

- We will go back to this when we introduce pointers.
  - For now, just treat an array as a sequence of variables.

Array declaration

- The grammar for declaring an array is

```
data type array name[number of elements];
```

- E.g., `int score[5];`
  - This is an integer array with five elements (the **array length/size** is 5).
  - Each **array element** itself is a **variable**.
  - The **index** starts at **0**! They are `score[0]`, `score[1]`, …, and `score[4]`.
- It occupies 4 bytes * 5 = 20 **continuous** bytes.
  - Try `cout << sizeof(score);`!

Address	Identifier	Value
0x20c648	score[0]	?
0x20c64c	score[1]	?
0x20c650	score[2]	?
0x20c654	score[3]	?
0x20c658	score[4]	?

Memory

An example

- We have written a program for 5 scores:

```
int score[5];
for (int i = 0; i < 5; i++)
  cin >> score[i];
for (int i = 0; i < 5; i++)
  cout << score[i] << " ";
```

- If we have 500 students:

```
int score[500];
for (int i = 0; i < 500; i++)
  cin >> score[i];
for (int i = 0; i < 500; i++)
  cout << score[i] << " ";
```

Array initialization

- Arrays are not initialized automatically.

```
int array[100];

for (int i = 0; i < 100; i++)
{
  cout << array[i] << " ";
  if (i % 10 == 9)
    cout << "\n";
}
```

Array initialization

- Various ways of initializing an array:
  - **`int dayInMonth[12] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};`**
  - **`int dayInMonth[] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};`** (size of **`dayInMonth`** will be 12)
  - **`int dayInMonth[12] = {31, 28, 31};`** (**nine** 0s)
  - **`int dayInMonth[3] = {1, 2, 3, 4};`** (error!)
- To initialize all elements to 0:
  - **`int score[500] = {0};`** (500 0s)

The boundary of an array

- In C++, it is **allowed** for one to "go outside an array".
  - No compilation error!
  - **May or may not** generate a **run time error**: If our program try to access a memory space allocated to another program, the operating system will terminate our program.
  - The result is **unpredictable**.
- A programmer must be aware of array bounds by herself/himself.

```
int array[100] = {0};

for (int i = 0; i < 500; i++)
{
  cout << array[i] << " ";
  if (i % 10 == 9)
    cout << "\n";
}
```

Memory allocation for arrays

- So what happens when we declare or access an array?
- When we declare an array:

```
int score[5];
```

  - The system allocates memory spaces accordingly to the type and length.
  - The array variable indicates the **beginning address** of the space.

```
cout << score; // 0x20c648
```

Address	Identifier	Value
0x20c648	score	?
0x20c64c		?
0x20c650		?
0x20c654		?
0x20c658		?

Memory

Memory indexing for arrays

- When we access an array element:
  - The array index indicates the amount of **offset** for accessing a memory space.
  - `score[i]` means to take the variable stored at "starting from `score`, offset by `i` units".

```
cout << score + 2; // 0x20c650
```

- So `score[i]` is **always accepted** by the compiler for any value of `i`.
  - Always be careful when using arrays!

Address	Identifier	Value
0x20c648	score	?
0x20c64c		?
0x20c650		?
0x20c654		?
0x20c658		?

Memory

Finding the array length

- Sometimes we are given an array whose size is not known by us.
- One way of finding the **array length** is to use **`sizeof`**.
  - It returns the total number of bytes allocated to that array.
- Suppose the array is named score, its length equals

```
sizeof(score) / sizeof(score[0]);
```

  - **`sizeof(score)`** is the total number of bytes allocated to the array.
  - **`sizeof(score[0])`** is the number of bytes allocated to the first element.

Finding the array length

- Example: Let's print out all elements in an array:

```
int array[] = {1, 2, 3};
int length = sizeof(array) / sizeof(array[0]);
for(int i = 0; i < length; i++)
  cout << array[i] << " ";
```

- When using **sizeof** to count the length of, e.g., an integer array:
  - Use **sizeof(a) / sizeof(a[0])**.
  - Do not use **sizeof(a) / sizeof(int)**.
- Why?

Example: finding the maximum

- How to find the **maximum** among many numbers?
- Suppose we want to write a program that:
  - Asks the user to input 10 numbers.
  - Once 10 numbers are input, prints out the maximum.

```
float value[10] = {0};
for (int i = 0; i < 10; i++)
  cin >> value[i];

// and then?
```

Example: finding the maximum

- Now the task is to find the maximum in **`value`**.
- In many cases, we write an **algorithm** to complete a task.
  - An algorithm is a step-by-step procedure that completes a given task.
- When designing an algorithm, we typically write **pseudocodes** first.
  - A description of steps in words organized in a program structure.
  - To ignore the details of implementations.
- How to find the maximum?
  - Compare the first two and find the larger one.
  - Use it to be compare with the third one.
  - And so on.

Example: finding the maximum

- One pseudocode for finding the maximum in a set is:

> Given a vector A of n numbers:
> ***for*** i from 0 to $n - 1$
> find the larger between A_i and A_{i+1}
> put the larger one at A_{i+1}
> output A_n

- What some drawbacks of this implementation (or algorithm)?

- Implementation:

```
// value: a size-10 float array
for (int i = 0; i < 9; i++)
{
  if (value[i] > value [i + 1])
  {
    float temp = value[i + 1];
    value[i + 1] = value[i];
    value[i] = temp;
  }
}
cout << value[9];
```

Example: finding the maximum

- Let’s record the current maximum at some other place:

```
float value[10] = {0};
for (int i = 0; i < 10; i++)
  cin >> value[i];

float max = value[0];
for (int i = 1; i < 10; i++)
{
  if (value[i] > max)
    max = value[i];
}
cout << max;
```

Good programming style

- It is suggested to declare a **constant** and use it to:
  - Declare an array.
  - Control any loop that traverse the array.
- Why?

```
const int VALUE_LEN = 10;

float value[VALUE_LEN] = {0};
for (int i = 0; i < VALUE_LEN; i++)
  cin >> value[i];

float max = value[0];
for (int i = 1; i < VALUE_LEN; i++)
{
  if (value[i] > max)
    max = value[i];
}
cout << max;
```

Things you cannot (should not) do

- Suppose you have two arrays **`array1`** and **`array2`**.
  - Even if they have the same length and their elements have the same type, you **cannot** write **`array1 = array2`**. This results in a syntax error.
  - You also **cannot** compare two arrays with **`==`**, **`>`**, **`<`**, etc.
- Why?
  - **`array1`** and **`array2`** are just two memory addresses!
- To copy one array to another array, use a loop to copy each element one by one.
  - For comparisons it is the same.

Things you cannot (should not) do

- Although allowed in Dev-C++, you should not declare an array with its length being a **nonconstant** variable.

```
int x = 0;
cin >> x;
int array[x]; // very bad!
```

  - This results in a syntax error in some compilers.
  - In ANSI C++, the length of an array must be **fixed** when it is declared.
  - Arrays with dynamic sizes will be discussed later.
- The index of an array variable should be an **integer**.
  - Some compiler allows a fractional index (casting is done automatically).

Outline

- More about variables
- **Arrays**
  - Single-dimensional arrays
  - **Multi-dimensional arrays**
- C strings: character arrays

Two-dimensional arrays

- While a one-dimensional array is like a **vector**, a two-dimensional array is like a **matrix** or **table**.
- Intuitively, a two-dimensional array is composed by **rows** and **columns**.
  - To declare a two-dimensional array, we should specify the numbers of rows and columns.

```
data type array name[rows][columns];
```

- As an example, let's declare an array with 3 rows and 7 columns.

```
double score[3][7];
```

Two-dimensional arrays

- `double score[3][7];`

	0	1	2	3	4	5	6
0	[0][0]	[0][1]	[0][2]				
1	[1][0]				[*x*][*y*]		
2	[2][0]						

  – `score[0][0]` is the 1st and `score[0][1]` is the 2nd. What are *x* and *y*?
- We may initialize a two-dimensional array as follows:
  – `int score[2][3] = {{4, 5, 6}, {7, 8, 9}};`
  – `int score[2][3] = {4, 5, 6, 7, 8, 9}; // 2 can be omitted.`

Example: matrix addition

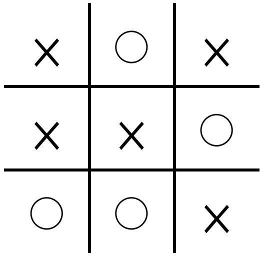
- Let's write a program to do matrix addition.

```
int a[2][3] = {{1, 2, 3}, {1, 2, 3}};
int b[2][3] = {{4, 5, 6}, {7, 8, 9}};
int c[2][3] = {0};

for (int i = 0; i < 2; i++)
{
  for (int j = 0; j < 3; j++)
    c[i][j] = a[i][j] + b[i][j];
}
```

Example: tic-tac-toe

- Let's write a program to detect the winner of a tic-tac-toe game:

```
int a[3][3] = {{1, 0, 1}, {1, 1, 0}, {0, 0, 1}};

for (int i = 0; i < 2; i++)
{
  if (a[i][0] == a[i][1] && a[i][1] == a[i][2])
  {
    cout << a[i][0] << endl;
    break;
  }
}
// then check for columns and diagonals
```



Embedded one-dimensional arrays

- Two-dimensional arrays are not actually rows and columns.
- A two-dimensional array is actually **several** one-dimensional arrays.

	0	1	2	3	4	5	6
score[0]	[0][0]	[0][1]	[0][2]				
score[1]	[1][0]						
score[2]	[2][0]						

- Try this:

```
int a[2][3];
cout << a << " " << a[0] << " " << a[1] << endl;
```

Embedded one-dimensional arrays

- `int a[2][3];`
  - `a[0][0]` is the first element.
  - `a[0][1]` is the second element.
  - `a[1][0]` is the **fourth** element.
- Two dimensional arrays are stored **linearly**.
  - And still **consecutively**.
- Try this:

```
int a[2][3];
cout << a << " " << a[0] << endl;
cout << a[1] << " " << a + 1 << endl;
cout << sizeof(a) << " " << sizeof(a[0]) << endl;
```

Address	Identifier	Value
0x20c648	a[0]	?
0x20c64c		?
0x20c650		?
0x20c654	a[1]	?
0x20c658		?
0x20c65c		?

Memory

Embedded one-dimensional arrays

- So for a two dimensional array **`score`**:
  - **`score[0]`** is the ____th one-dimensional array.
  - **`score[0][j]`** is the ____th element of the ____th one-dimensional array.
  - **`score[i]`** is the ____th one-dimensional array.
- Which description is more accurate?
  - There is an array having three rows and seven columns.
  - There is an array having three rows, each having seven elements.
- All these one-dimensional arrays must be of **the same length**.
  - Two-dimensional arrays with various row lengths can be built with pointers.

Multi-dimensional arrays

- We may have arrays with even higher dimensions.
  - `char threeDim[3][4][5];`
  - `Int eightDim[3][4][5][6][1][7][4][8];`
- Difficult to imagine and use.

Outline

- More about variables
- Arrays
- **C strings: character arrays**

Strings

- In many applications, we need some ways to handle **strings**.
- E.g., in an address book application, if we do not have strings:
  - We cannot store names.
  - We cannot store phone numbers.
  - We cannot store addresses.
- Strings can be implemented in two ways:
  - C strings as **character arrays**.
  - C++ strings as **objects**.
- Today we will introduce C strings.

C strings as character arrays

- A C string is a character array.
- We have already used string with **`cout`**:

```
cout << "Hello world";
```

  - **`"Hello world"`** is a string.
- A string is contained in a pair of double quotation marks.
  - A character is contained in a pair of single quotation marks.

C strings v.s. other arrays

- C strings are nothing but a character arrays.
- However, character arrays are "special".
- For example:

```
int array[10];
cin >> array;
return 0;
```

```
char array[10];
cin >> array;
return 0;
```

  – While the first one results in a compilation error, the second one can run!

C strings v.s. other arrays

- For an array **A**, if we do **cin >> A**:
  - If **A** is of other types, this is not allowed.
  - But for a character array, this allows us to input the string.

```
char str[10];
cin >> str; // if we type "abcde"
cout << str[0]; // 'a'
cout << str[2]; // 'c'
```

C strings v.s. other arrays

- For an array **`A`**, if we do **`cout << A`**:
  - If **`A`** is of other types, this will print out it memory address.
  - But for a character array, this prints out the whole string (some exceptions will be discussed later).

```
char array[10] = {'a', 'b', 'c'};
cout << array; // "abc"
return 0;
```

Input/output of a C string

- Because it is too often for a program to input/output a string, the C++ standard **implements** **<<** and **>>** for character arrays in a **special** way.
  - **<<** and **>>** are operators.
  - An operator can do different things according to the input data types.
  - This is called **operator overloading** and will be discussed in this semester.
- The implementation of C string I/O needs to be investigated in more details.
- Before that, let's see how to declare a C string.

C string declaration and initialization

- A C string is declared as a character array.
  - `char s[100];`
- A C string may be initialized with a double quotation.
  - `char s[100] = "abc";`
- In this case, a **null character** `\0` is appended at the end **automatically**.
  - `\0` is an escape sequence. It marks the **end of a string**.
  - The length of the string stored in `s` is 3 + 1 (`\0`).
- When you declare a character array of length n, you can store a string of length at most $\boldsymbol{n-1}$.

Understanding the null character

- The null character is `\0`, not `\o` or `\O`.
- From the system's perspective, a null character marks the end of a string.

```
char a[100] = "abcde FGH";
cout << a << endl; // abcde FGH
char b[100] = "abcde\0 FGH";
cout << b << endl; // abcde
```

- One may also initialize a C string by assigning multiple characters.
  - `char s[100] = {'a', 'b', 'c'};`
  - **No** null character will be appended.

String assignments

- Assignments with double quotations are allowed only for initialization.
  - `char s[100];`
    `s = "this is a string"; // compilation error!`
- One may assign values to a string by assigning characters.
  - `s[0] = 'A'; s[1] = 'B'; s[2] = 'C';`
- One may assign values by `cin >>`.
  - `cin >> s;`
  - A null character will be appended.

```
char c[100];
cin >> c; // "123456789"
cin >> c; // "abcde";
cout << c << endl; // "abcde"
c[5] = '*';
cout << c << endl; // "abcde*789"
```

Two strange cases

```
char a[5];
cin >> a; // "123456789"
cout << a; // "123456789" or an error
```

- C++ does not check **array boundary**!
- We may or may not touch those memory spaces used by other programs/variables.
  - If a protected space is touched, an error occurs and our program is shutdown.
  - If not, `cout <<` prints out **the whole string** until the **end of a string**, which is marked by a `\0`.

Two strange cases

```
char a1[100];
cin >> a1; // "this is a string"
cout << a1; // "this"
```

- Is it because a white space is treated as an end of C strings?
- No!

```
char a2[100] = {'a', 'b', ' ', 'c', '\0', 'e'};
cout << a2; // ab c
```

- Then why?

`cin >>` vs. `cin.getline()`

- When **`cin >>`** reads a white space, it treats that as the end of input and thus only "this" is stored into the array.
  - The same thing happens for a new line or a tab.
- To input a string with white spaces, use `cin.getline()`.
  - Treat is as a function defined in **`<iostream>`**.
  - It treats only end of line as the end of input.

```
char a[100];
cin.getline(a, 100); // "this is a string"
cout << a << endl; // "this is a string"
```

Useful functions for C strings

- Look at your textbook or websites to find some useful function.
- In `<cstring>`:
  - `strlen()`, `strcat()`, `strcmp()`, `strchr()`, `strstr()`, etc.
- In `<cstdlib>`:
  - `atoi()`, `atof()`, etc.
- To convert a value to a C string, we will wait until we introduce C++ strings.