LECTURE III

C++ Programming

SECTION I

Programs and Programming Languages

What is a Program?

- A computer **program** is a **sequence of instructions** for a computer to execute
- **Software** is a **set of programs** and **data** that are used to perform a specific task on the computer
  - Ex) MS Word, Discord, Minecraft
  - Contrasts from **hardware**, which is the collection of **physical components** that make up the system

Programming Languages

- A **programming language** is a **notation** for the instructions we give to the computer
- Just like a human language, a programming language is **defined by grammar**
  - There is **syntax** - a **structure** or way of organizing symbols in the language
    - Ex) In English, sentences are *structured* as follows:
      - Subject + Verb + Predicate
  - There are also **semantics** - the **meaning** of a set of symbols or their arrangement

Programming Languages (Cont'd)

- Popular programming languages include **C++**, **Java**, **Python**, **Javascript**
  - Each of these languages have a **unique grammar** (with some overlap)
  - Each have **strengths and weaknesses**
    - Ex) Javascript is widely used in websites but isn't used as much for desktop applications
    - Ex) Python is great for quick scripting but more challenging when writing software that interfaces with hardware or manages memory






Machine Language

- Computers execute instructions in a **machine language** or **machine code**
  - Machine code is written in **binary** 1s and 0s, which is converted into HIGH and LOW voltages on the hardware level
- Human-readable programming languages must be **translated** into machine language that the computer can execute

Source Code

```
a = "hello";
b = a + "!";
```

Translation

Machine Code

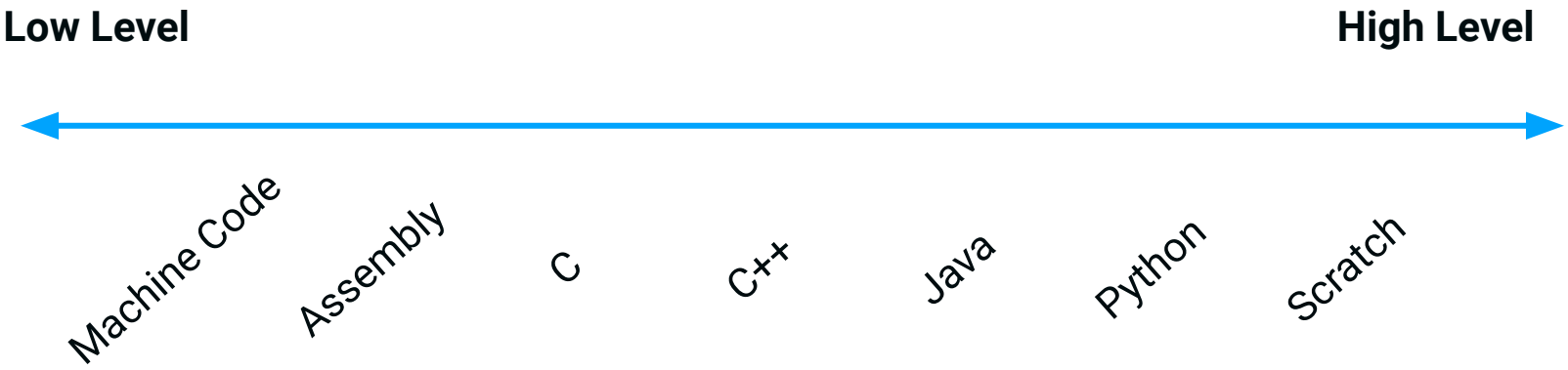
```
1011 1010
1010 1011
0110 1011
```

High vs Low Level Languages

- **High-level** programming languages provide strong abstractions from the computer hardware
  - The language may automate memory management
  - Ex) **C**, **C++, Python**, **Java**
- **Low-level** programming languages provide little to no abstractions and tend to be structurally similar to machine language instructions
  - Ex) **Assembly** languages, **Machine languages**

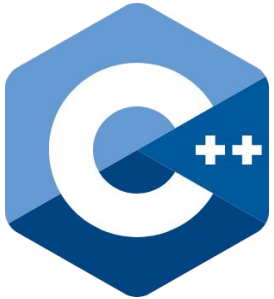
High vs Low Level Languages (Cont'd)

There is a **spectrum** of low to high level programming languages:



C++ Programming Language

- C++ is a **general-purpose** programming language
  - Used to write operating systems, video games, **embedded software**, etc.
- It was designed as a **superset of the C programming language**
  - Much of what you write in C can run in a C++ program
- Why would we focus on C++?
  - We will eventually use **Arduino**, which is based on C++

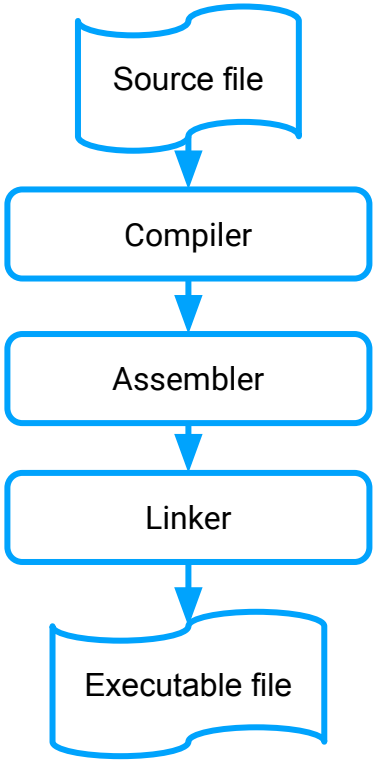


SECTION II

Compilation Process

Compilers, Assemblers, and Linkers

- We must **translate** C++ source code into machine code using a program called a **compiler**
- Technically, translation is handled by multiple programs:
  - A **compiler** converts C++ source code into assembly language
  - An **assembler** converts the assembly code into machine code
  - A **linker** takes the machine code files and “links” them together into one **executable file**



Target Architectures

- Machine code is **architecture-dependent**
  - Ex) Intel or AMD-powered computers use **x86-64 machine code**, many phones are ARM-based which use **ARM64 machine code**
    - Intel, AMD, and ARM are all processors which execute program instructions within the computer (to be discussed in future lectures…)
- The compilation process must have a **target architecture**
  - Ex) For C++ programs to run on Intel machines, they must be compiled to an x86-64 executable

SECTION III

Variables, Statements, and Operators

Statements

- Programs are composed of **statements**
- A **statement** is an instruction that causes the program to perform some action
  - **Syntax**: statements in C++ often **end with a semicolon (;)**

```
int n = 1;                    // declaration statement
n = n + 1;                    // expression statement
return 0;                     // return statement
```

Variables

- **Variables** are containers for data values
  - C++ variables have **types** - integers, characters, booleans, etc.
- Variables must be **declared**

```
int a;              // integer declaration
int b, c, d;        // three variable integer
declaration
```

- Variables are **assigned** values

```
a = 3;              // copy assignment to a
b = 102324325;
```

Variables (Cont'd)

- **Initialize** your variables when declaring them

```
int a = 50;              // integer variable
initialization
char c = 'w';
```

- **Syntax**: `type variableName = value;`
- **Naming Convention:** Variable names are written in **camelCase**
  - The first word is not capitalized and the first letter of all the following words is capitalized

Basic Data Types

Type	Definition	Example
`int`	Integer	`-2, 0, 1, 300`
`unsigned int`	Positive Integer	`0, 1, 5, 6`
`char`	Character	`'c', 'g', 'w'`
`float`	Floating Decimal	`1.2367`
`bool`	Boolean	`True, False`

Operators and Expressions

- **Operators** are used to perform operations on variables and values
  - Some are for arithmetic, assignment, comparison, etc.
- An **expression** is a combination of values, variables, and operators that **evaluate** to one single value

```
b + 5;                      // example expression
a + 4 / 5 - b * c;
```

Arithmetic Operators

Operator	Name	Definition	Example
+	Add	Adds two values together	`x + y`
–	Subtract	Subtracts one value from another	`x – y`
*	Multiply	Multiplies two values together	`x * y`
/	Divide	Divides one value from another	`x / y`
%	Modulus	Remainder of Division	`x % y`
++	Increment	Increases value of a variable by one	`x++`
––	Decrement	Decreases value of a variable by one	`y––`

Assignment Operators

Operator	Example	Equivalent Statement
=	`x = y`	
+=	`x += 5`	`x = x + 5`
-=	`x -= 5`	`x = x - 5`
*=	`x *= 5`	`x = x * 5`
/=	`x /= 5`	`x = x / 5`

Comparison Operators

Operator	Name	Example
==	Equal to	`x == y`
!=	Not equal to	`x != y`
>	Greater than	`x > y`
<	Less than	`x < y`
>=	Greater than or equal to	`x >= y`
<=	Less than or equal to	`x <= y`

Logical Operators

Operator	Name	Example
`&&`	Logical AND (Both True)	`x && y`
`||`	Logical OR (Either is True)	`x || y`

- Expressions with **logical** or **comparison** operators evaluate to **True** or **False**

SECTION IV

Control Flow

If Statement

```
if (condition) {
  // block of code to be executed if the condition is true
}
```

- The **if statement** is a type of conditional statement
- If the **condition** evaluates to true, the program executes the block below
- The **block** is the set of statements enclosed by { }

Else Statement

```
if (condition) {
  // block of code to be executed if the condition is true
}
else {
  // code that executes if the condition is false
}
```

- An **else statement** is an optional statement that executes only when the condition is **false**

If-Else Statement

```
int x = 2;
if (x > 1) {
  x = 1;
}
else {
  x = 6;
}
```

Ex) Suppose the program executes this code. What is the value of x?

- The condition (`x > 1`) evaluates to **`True`**, so the if-block executes
- The else statement is skipped
- **Solution**: `x = 1`

Else If Statement

```
if (condition) {
  // block of code to be executed if the condition is true
}
else if (condition2) {
  // code that executes if the previous conditions are
  // false and condition2 is true
}
```

- An **else if statement** is an optional statement that executes *only* if the **previous conditions are false** *and* the **new condition is true**

If-Else Statement

I/A

```
int x = 5;
if (x > 2) {
  x = 1;
}
else {
  x = 6;
}
```

What is the value of **x** after the code executes?

A. `x = 1`

B. `x = 2`

C. `x = 5`

D. `x = 6`

While Loop

```
while (condition) {
  // code to be executed while the condition is true
}
```

- The **while loop** executes the block of code repeatedly *while* the condition is **true**; the loop ends when the condition is **false**
- The **condition** is evaluated at the beginning of each loop

While Loop (Cont'd)

```
int x = 1;
while (x != 5) {
  x++;
}
```

Ex) Suppose the program executes this code. What is the value of x?

- The while loop executes as long as `x != 5`
- **Solution**: `x = 5`

For Loop

```
for (init-statement; condition; end-expression) {
  // code to be executed while the condition is true
}
```

- The **for loop** executes the block of code repeatedly until the condition is **false**
- The **init-statement** is executed once when the for loop starts
- The **condition** is evaluated at the beginning of each loop
- The **end expression** is executed at the end of each loop

For Loop (Cont'd)

```
int sum = 0;
for (int i = 0; i < 10; i++) {
  sum += i;
}
```

Ex) Suppose the program executes this code. What is the value of sum?

- The for loop executes 10 times; `i` increments once each loop
- **Solution**: `sum = 0 + 1 + 2 … + 8 + 9 = 45`

For Loop (Cont'd)

I/A

```
int x = 2;
for (int i = 1; i <= 3; i++)
{
  x = x-i;
}
```

What is the value of **x** after the code executes?

A. `x = 2`

B. `x = -7`

C. `x = -1`

D. `x = -4`

SECTION V

Arrays

Arrays

- An **array** is a **series of elements** of the **same type** that is referenced with a single identifier
- **Syntax**:

```
type arrayName[size];
```

- The array **size** or **number of elements** is fixed at declaration (for static allocation)
- By default, arrays are **uninitialized** (none of its elements are set) at declaration
    - Best practice is for us to initialize the elements at this time

Array Initialization

```
int foo[6];
```

Array declaration without initialization

```
int foo[6] = {9, 2, 5, 4, 8, 11};
```

Array declaration with initializer list

```
int foo[]{9, 2, 5, 4, 8, 11};
```

Universal initialization does not require an equal sign or an explicit array size; they are implicit

Array Access

- Elements of the array can be accessed using an **index** starting from `0`
  - Ex) An array with a size of `5` has indices ranging from `0` to `4`
- **Syntax**:

```
variableName[index]
```

```
foo[2] = 76;
```

Assigns the *third* element of **`foo`** to `76`

```
x = foo[2];
```

Assigns `x` to the *third* element of **`foo`**

Array Access

I/A

```
int x[3] = {5, 2, 4};
if (x[1] > 3) {
  x[0] = 3;
}
```

What is the value of **`x[0]`** after the code executes?

A. `x[0] = 5`

B. `x[0] = 2`

C. `x[0] = 3`

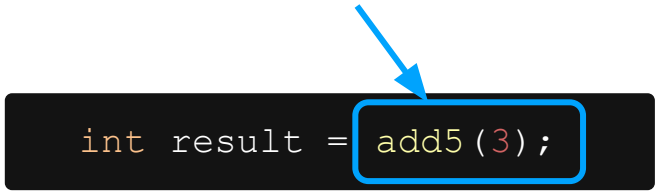
D. `x[0] = 4`

SECTION VI

Functions and Scope

Functions

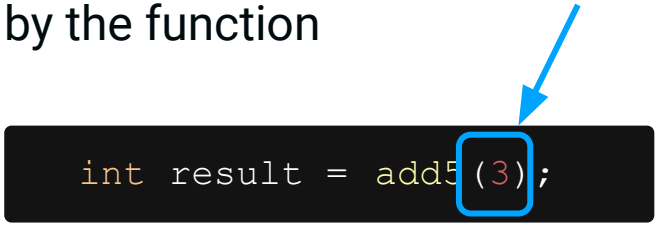
- A **function** is a reusable sequence of statements designed to do a particular job
- We use a **function call** to tell the program to execute the function



- The example above includes a call to some function **`add5()`**

Functions (Cont'd)

- Function calls include **arguments** which are used and/or manipulated by the function



- After the function executes, a **return value** replaces the original function call
  - The example function **`add5()`** *returns* the argument + 5

Function Declaration

- A **function declaration** is needed to designate a new function

```
returnType identifier(paramType paramName);
```

- The **return type** is the **data type** of the return value
  - Some functions have **no return value**, so the return type is **void**
- The **identifier** is the **name** of the function
  - **Naming Convention:** Function names are written in **camelCase**

Function Declaration (Cont'd)

```
returnType identifier(paramType paramName);
```

- A function has **parameters** which are assigned/bound to the arguments of the function call
  - Functions may have **multiple parameters** or none
    - **Syntax**: Each parameter is separated by a **comma** (,) in the parenthesis
  - These parameters are used as **variables** in the body of the function definition…

Function Definition

- The **function definition** is where the function's code is implemented

```
returnType identifier(paramType paramName) // function header
{
    // function body - where the function's code goes
}
```

- The **header** must match the function declaration
- The body must contain a **return statement** if the return type is not void

Function Definition (Cont'd)

```
int add5(int x)
{
    return x + 5;
}
```

- The example function **`add5()`** has the `int` parameter **`x`**
- The function **returns** an `int`, which is the sum of **`x`** `+ 5`

```
int result = add5(3);
```

This call **returns 8**

Function Definition (Cont'd)

I/A

```
int myFunc(bool a, int b, float c)
{
    if (a)
    {
        return b;
    }
    return 0;
}
```

Which is the correct function call for myFunc?

A. `myFunc(false);`

B. `myFunc(true, 3, 0.23);`

C. `myFunc(3, 0.58);`

D. `myFunc(false, 3.10, 2);`

Main Function

```
int main()
{
    // This is the starting point for program execution.
    // Write the code you want to run here.
}
```

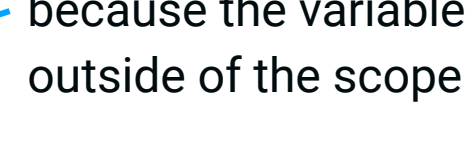
- Every C++ program starts at **`main()`**
  - You *must* define the main function. There is no declaration; it's built in.
- Write the code you want to run in the body of **`main()`**

Local Scope

- Variables created within functions and loops are called **local variables**
- **Local variables** are visible *only* within the **scope** of that function or loop after being declared
    - meaning… local variables cannot be accessed outside of the scope

```
int add5(int x)
{
    return x + 5;
}

x = 2;
```



The code here results in an **error** because the variable **`x`** is referenced outside of the scope of **`add5()`**

Global Scope

- Variables created outside functions and loops are called **global variables**
- **Global variables** have **file scope**, which means they are visible *anywhere* in the file *after* being declared
    - You **cannot reference an identifier before its declaration**
- It is best practice to only declare global variables with the `const` keyword (for constant variables)

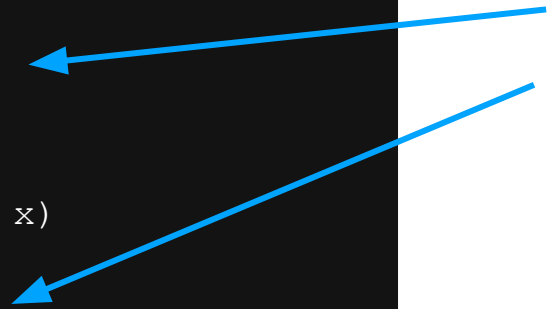
```
const float PI = 3.14159;
```

Global Scope (Cont'd)

```
const float PI = 3.14159;

int addPi(int x)
{
    return x + PI;
}

int subtractPi(int x)
{
    return x - PI;
}
```



The variable `PI` is **accessible at function scope** because it was **defined globally** before it was referenced

SECTION VII

Classes

Classes

- A **class** is a user-defined data type
- Classes may contain **member variables** and **functions**
- **Instances** of a class, or **objects**, are created as follows:

```
className objectName(arg1, arg2, ...);
```

- Objects are created using a special member function called a **constructor**, whose arguments are given at declaration
- To initialize the object as a default version ditch the parentheses

Classes (Cont'd)

```
Oven easyBake;   // instance of the Oven class, default initialized
Oven myOven("Red"); // another oven initialized with a constructor

easyBake.contents = "cookie dough"; // accessing a member variable
easyBake.setTemp(450); // calling a member function
easyBake.bake();
```

- We have created an object of the class **`Oven`**, oven called **`easyBake`**
- **`easyBake`** has member variables and functions which can be accessed using the **dot (.)** operator

SECTION VIII

Includes, iostream, and string

#include

- **#include** is a directive which inserts to contents of a file into the current file
- A **header file** contains declarations of classes, functions, and variables that can be accessed using #include

```
#include <iostream>
```

This example is an include of a header file which contains functionality for inputting/outputting text to the terminal

iostream

```
#include <iostream>
```

- The **iostream** header gives us access to a library of objects and functions that support input/output
- Input/output is managed through **streams** - sequences of bytes that represent data
- We use **standard output stream** object `std::cout` for output to the terminal
- The **standard input stream** object `std::cin` is for input from the terminal

std::cout

- We can insert data into **`std::cout`** using the **stream insertion operator** **<<**

```
int x = 4;
std::cout << x;
```

`x` is *inserted* into the standard output stream

```
int x = 4;
int y = 9;
std::cout << x << 7 << 'w' << y;
```

We can insert more data in the same statement

std::cout (Cont'd)

- We can insert data into **`std::cout`** using the **stream insertion operator** **<<**

```
int x = 4;
std::cout << x;
```

Output: `4`

```
int x = 4;
int y = 9;
std::cout << x << 7 << 'w' << y;
```

Output: `47w9`

std::cout (Cont'd)

- We use several **escape sequences** - special character combinations which carry additional meaning beyond their literal values - to enhance the output
- Start a **new line** using `'\n'` or `std::endl`

```
std::cout << 4 << '\n' << 6;
```

```
std::cout << 4 << std::endl << 6;
```

Output:

```
4
6
```

- Use `'\t'` to **insert a tab**

std::cin

- We can read data from **`std::cin`** using the **stream extraction operator** **>>**

```
int x;
std::cin >> x;
```


Input is *extracted* from the standard input stream and assigned to **`x`**

- **`std::cin`** reads until it hits **any whitespace** (space, tab, or newline)
  - If you type `321 5` into the terminal while executing the code above...

    `x` will only be assigned to `321`

std::string

```
#include <string>
```

- The **string** header gives us support for managing “strings” of characters, which make text
- We can create `std::string` objects and assign them to **string literal values**

```
std::string str = "Test String";
```

std::string (Cont'd)

- Strings can be **concatenated** with the + or += operators

```
std::string a = "Apple";
std::string b = "Banana";
std::string c = a + b + "Orange";
```

c == "AppleBananaOrange"

- Strings can be **indexed** just like arrays!
  - They are technically character arrays

```
std::string a = "Apple";
a[1] = 'm';
```

a == "Ample"

SECTION IX

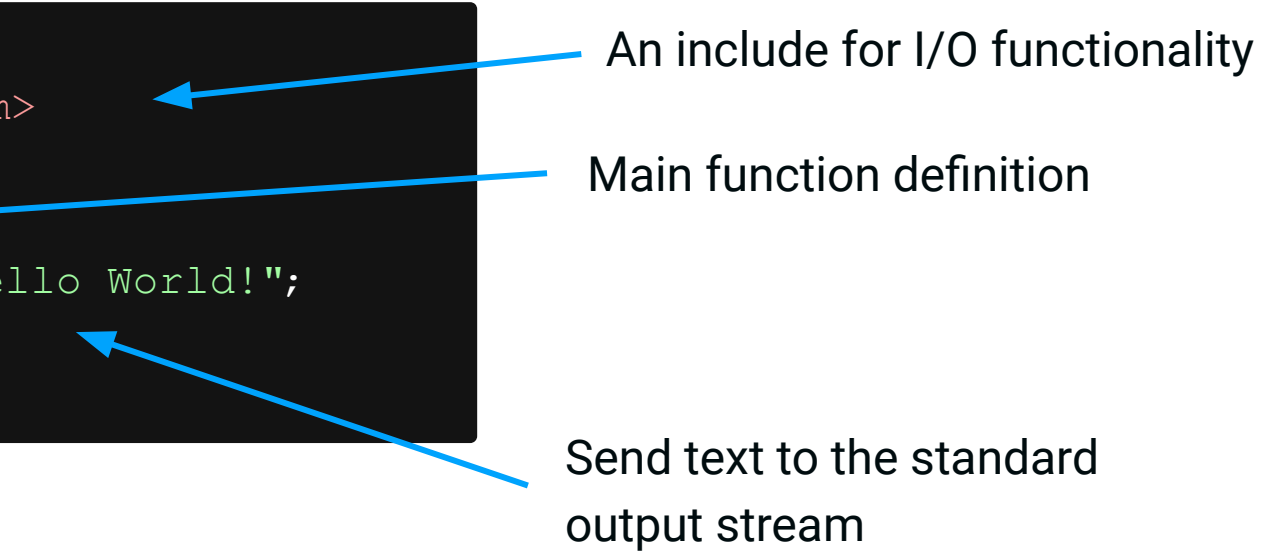
Your First Program

Hello World!

Let’s use everything we’ve learned to write a program that prints some text to the terminal…

```
#include <iostream>

int main() {
  std::cout << "Hello World!";
}
```



SECTION X

Integrated Development Environments

Integrated Development Environments

- An **integrated development environment** (**IDE**) is a suite of applications used for software development
  - It is *more* than a text editor for you to write source code
  - It includes a **source-code editor**, **compiler**, **debugger**, and **automation tools**
    - When you create a program, you will write and edit it in the **source-code editor**
    - The IDE will come with a built-in **compiler** for code translation
    - The **debugger** will help troubleshoot errors and unexpected behavior while the program is running

Popular IDEs

- Common **IDEs for C++** developers include:
  - Visual Studio
  - CLion
  - XCode

- There are multi-language **cloud-based IDEs** as well:
  - Replit
- Learn more about how to use select IDEs in our workshop video!

SECTION XI

C++ Extras

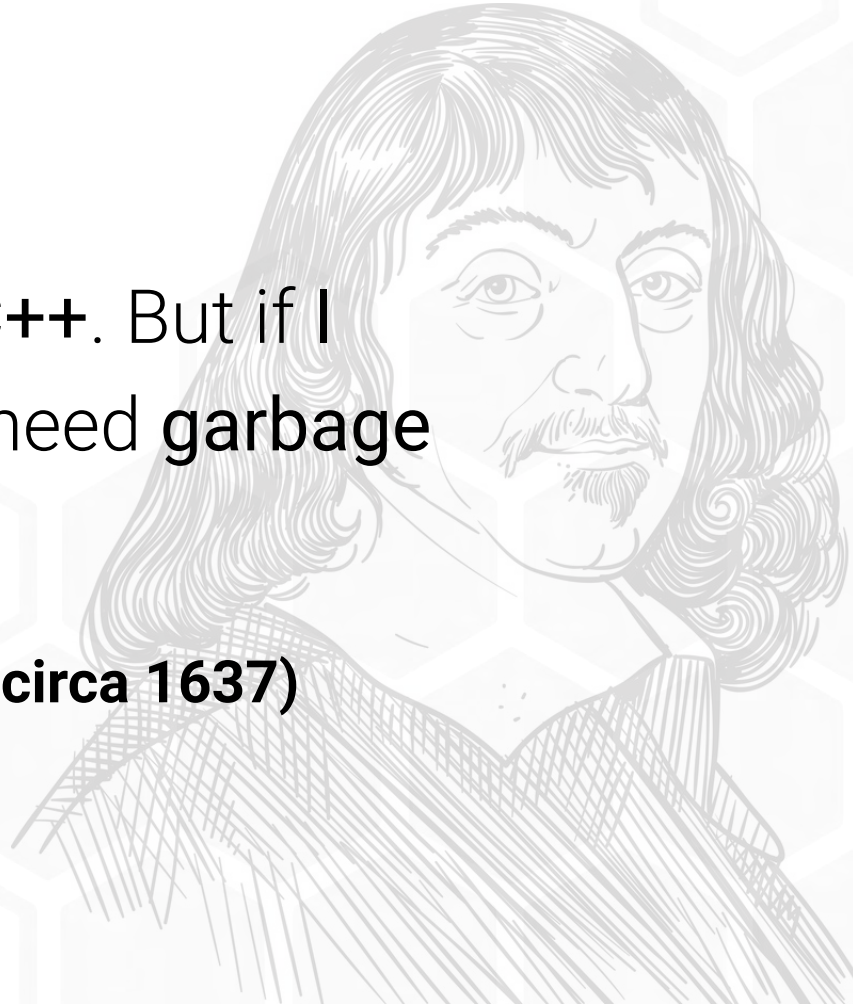
Bonus Topics

- Structs
- Function overloading
- Recursion
- Pointers
- Dynamic memory allocation
- Type casting
- Go to www.learncpp.com and learn more!

“**I think**, therefore **I use C++**. But if **I think too much**, I might need **garbage collection**.”

René Descartes (circa 1637)

Famous Misquotes



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