**Beginning C++ Programming by Frank J. Mitropoulos**My Course Notes

Troubleshooting

* CMake/NMake errors:
* Ensure that your antivirus isn’t blocking the build process by quarantining files.
* Restart computer.
* “Error: could not load cache”:
* Tools > CMake > Reload CMake Project.

Introduction

* There are multiple versions of C++: C++98, C++03, **C++11**, **C++14**, and **C++17**. The digits represent the year that version was released. The former two versions are referred to as classic C++, while the latter three are referred to as modern C++.
* C++98 was the first official standard. C++11 added many new features to the language. The other versions mainly corrected issues with the language or simplified pre-existing features.
* The process to create run an application is as follows:
* The developer inputs C++ code into header (.h) and source (.cpp) files in an IDE.
* The pre-processor looks for pre-processor directives such as *#include* and processes them.
* The compiler converts the high-level C++ code into low-level machine/binary/object code (.obj).
* The linker combines our code with other libraries and outputs an executable (.exe).
* The course will use CodeLite since it’s free, but the instructor stated that CLion by JetBrains is his IDE of choice. I have opted to use CLion as I have access to it and think highly of JetBrains.

Installation and Setup

* You can execute C++ code through an IDE, the CLI (command line interface), or via a website such as ‘repl.it’.

Curriculum Overview

* No notes taken.

Getting Started

* Code completion aids the developer by predicting what they will input and suggesting it to save time.
* Pre-processor directives don’t end in a semi-colon.
* *cout* is tied to the console and is used to output data.
* *<<* is the insertion operator that outputs the following data.
* Text between quotation marks represents a string literal: e.g. “Hello world!”.
* Statements end in a semicolon.
* *‘return 0;*’ in *main()* to indicate that there weren’t any problems.
* *cin* is also tied to the console and is used to input data from the user.
* *>>* is the extraction operator that stores the input.
* **Variables** store data.
* To declare a variable state its type and give it a name, e.g. ‘*int favourite\_number;*’.
* *#include <iostream>* includes the input/output library where *cout* and *cin* are defined.
* *endl* prints a new line and flushes the buffer.
* To build means to compile it and link it. This results in object files. The build process saves time by only building the files that it has to.
* The clean process removes the object files, but then you must build your program again.
* **Compiler errors** occur when the code doesn’t follow programming rules. It does this by identifying syntax and semantic errors.
* **Syntax error** refers to when the structure of the code is incorrect, e.g. ‘*cout << “Errors << endl*’ in this case the trailing quotation character is missing.
* **Semantic error** refers to when the structure is correct, but the code is undefined, e.g. ‘*int a = b + c’* if *a* and *b* are *int*s and *c* is a person then it may not make sense to add them.
* Making one error will lead the compiler to detect many errors. So fixing one error will resolve many compiler errors.
* **Compiler warnings** occur when code can be compiled, but has potential issues, e.g. printing an uninitialized variable ‘*int data; cout << data;*’.
* Both warnings and errors should be avoided whenever possible.
* **Linker errors** occur when libraries or object files are missing.
* **Runtime errors** occur when the program is running, e.g. dividing by zero, file not found, out of memory, etc. These can crash the program. To crash means that the program ended abruptly. Exception handling is used to deal with runtime errors.
* **Logic errors** occur when the code is technically correct, but the logic behind it is incorrect thus allowing the program to do something it shouldn’t do.

Structure of a C++ Program

* **Keywords** are reserved terms that hold special meaning in programming languages. Their meaning can’t be redefined in any way, e.g. *return, int,* etc. C++ has around 90.
* **Identifiers** are names given by the programmer, e.g. *main, include, my\_variable, cout*, etc.
* **Operators**accept one or more operands and perform an action with them, e.g. *+, -, <<, %, /, ^, &&, ::,* etc.
* **Pre-processor directives**tell the pre-processor program what to do, e.g. *#include <iostream>* tells the pre-processor to place the contents of that source file in its place. It also replaces the comments with a space.
* **Comments** allow the programmer to describe meaning or explain themselves next to the code. *//* is used to place a single-line comment, everything on that line is ignored by the compiler. */\* … \*/* is used to place a multi-line comment, everything in between is ignored.
* Ideally code is self-documenting and easy to read. Avoid unnecessary comments as it makes the code harder to read.
* All C++ programs must have one *main* function. It’s where execution begins in the program. Returning 0 indicates that the program terminated successfully.
* There are two acceptable function signatures for *main*:

|  |  |
| --- | --- |
| int main() {  return 0;  }  Program.exe | int main(int argc, char \*argv[]) {  return 0;  }  Program.exe argument1, argument2 |

The first signature is for when the program doesn’t accept any arguments, the second signature is for when the program does.

* *argc* counts the number of arguments provided, *argv* (argument vector) contains the value of each argument. These can be provided from the command-line. A vector refers to data in a one dimensional array.
* *main* is a function that is called by the operating system. A **function** is a name that refers to a block of code.
* **Namespaces** allow grouping code to avoid naming conflicts.
* Example: A library imported from a company might have their own definition of *cout*, however with the use of namespaces you’ll be able to specify exactly which one you want to use: *std::cout* or *company::cout*.
* *std* is the name of the standard namespace which contains code from the STL.
* If you don’t foresee any naming conflicts, then you can use a **usingdirective**, e.g. ‘*using namespace std;*’ now you won’t have to type ‘*std::*’ before using identifiers declared in the *std* namespace.
* This isn’t recommended in large programs due to the potential increase in naming conflicts. Instead use a **using declaration** in which you specify the identifier directly, e.g. *using std::cout*.
* Using directives and declarations can be defined at global scope or block scope.
* *cout, cin, cerr,* and *clog* are objects representing streams. A stream is a sequence of a data type, e.g. a string is a sequence of characters.
* To print a new line either insert *endl* or *“\n”* escape sequence. The *endl* stream manipulator also flushes the buffer.
* *cout, cin, cerr,* and *clog* can be chained so that multiple data can be input or extracted.
* White space is ignored by *cin*’s extraction operator. The data input must match the type of variable the data is being stored in.
* *double* contains a real number, such as 2.5, 5, -1, etc.
* Data entered into the command line is stored in a buffer. Data exists in the buffer until it is read so it may be read unpredictably unless the buffer is periodically cleared.

Variables and Constants

* RAM is a contiguous block of memory that stores program instructions and data. Each memory cell has an associated location to reference it. Low level languages work directly with these locations and move data around. Higher level languages let you use variables to associate useful names to these locations.
* **Variable**is an abstraction for a memory location. They have a type (int, string, person, etc), name (age, name, bob, etc), and content (21, “bob”, etc). They must be declared before the are used, e.g. ‘*int age; age = 12*’, or *int age = 12*. A variable’s content can vary/change.
* The type tells the compiler what data can be stored in the variable. C++ is **statically typed** meaning that the type is checked at compile time. Some languages are **dynamically typed** meaning that the type is checked at runtime.
* Variables names can contain letters, numbers, and underscores. Can’t begin with numbers. Cannot use C++ keywords. Cannot redeclare a name in the same scope. C++ is case sensitive.
* Be consistent with naming conventions, e.g. camelCase vs. my\_variable. Use meaningful names that are not too short, not too long. Never use variables before initialising them. Declare variables close to when you actually need them in code to make it clear.
* There are three ways to declare and initialize variables. C-like initialisation: *int age = 21*. Constructor initialisation: *int age (21)*. C++11 list initialisation: *int age {21}*.
* Using uninitialised variables is dangerous because the variable just has the value/content that was already at the given address. There’s no way to predict what a previous program set it too.
* **Local variables** are variables defined within a code block as their scope/visibility is limited to the statements within that block.
* **Global variables** are variables defined outside of any code block. They are called this because they have global scope/visibility and can be accessed from any part of the program.
* Global variables are automatically initialised to zero, unlike local variables.
* Global variables should be avoided as they make code difficult to debug.
* The compiler first looks locally to find the variable, it then goes up in scope until it ultimately checks the global scope for the variable.
* Variables in different scopes can have the same identifier. To specify a variable from global scope use :: without specifying a namespace.
* Primitive/fundamental data types are defined by the language itself.
* The size and precision of these data types depends on the operating system and compiler.
* The *climits* include contains information about the size and precision of various datatypes for the given compiler.
* Type sizes are expressed in bits, the more bits the more values can be stored and the more storage is required.
* One bit can represent 2 values, 8 bits can represent 28 values, 16 bits > 216, etc.
* 8 bits is 1 byte, 16 bits is 2 bytes, etc.
* Character types are used to represent single characters, e.g. ‘A’, ‘X’, ‘@’, etc. Wider types are used to represent wide character sets. Single quotes are used for characters.
* *char* is one byte, c*har16\_t­* is at least 2 bytes, *char32\_t* is at least 4 bytes, and *wchar\_t* can represent the largest available character set.
* Integer types are used to represent whole numbers, e.g. 5, 112, -23, 0, etc. There are signed and unsigned versions. Integers are *signed* by default so you don’t need to type that. *short* and *long* are *int* by default so you don’t need to type that either.
* *short* and *int* are at least 2 bytes, *long* is at least 4 bytes, and *long long* is at least 8 bytes.
* Types: *short, int, long, long long, unsigned short, unsigned, unsigned long, unsigned long long.* Unsigned types move their negative range to their positive range, meaning you can’t represent negative numbers, and get double the positive range.
* Floating types are used to represent real numbers: whole and fractional, e.g. 5, -2.5, 3.14159, etc.
* *float* is typically accurate to 7 decimal digits / 4 bytes, *double* to 15 / 8 bytes, and *long double* to 19 / 12 bytes.
* Boolean type represents true and false, zero is false, and none-zero is true. *bool* is usually 1 byte. *true* and *false* are generally used in place of numbers.
* You can use single quotes to split a large number, e.g. *long value = 123’456’789*. The quotes can be anywhere inside the number and not outside or adjacent to another quote.
* If you go over the range of a type, e.g. *short value = 70’000* this results in an **overflow**. The resulting value is the overflow amount. You can overflow by going over the maximum or minimum values for the data type.
* Storing a floating type in an integral type results in **truncation**. Only the integer is kept, the decimals are truncated. In effect, it always rounds down.
* A narrowing conversion is when a large type is stored in a smaller type, e.g. *long* to *short*, or *float* to *int*. The list initialiser syntax prevents this at compile time. It also prevents overflow and truncation errors. The opposite of a narrowing conversion, is widening.
* You can express a literal using scientific notation, e.g. *2.7e2* is 2.7x102.
* The *sizeof* operator determines the size, in bytes, of a variable/type/array/object/etc. Examples: *sizeof(int), sizeof(double), sizeof(my\_variable),* and *sizeof my\_variable*. It gets this information from *<climits>* and *<cfloat>*.
* **Constants** are mostly identical to variables except that their value/content can’t be changed once it’s set.
* Constants make it clear to programmers that the content should never be changed, e.g. months in a year are always 12. Reassigning a declared constant is a compile time error.
* There are many types of constants: literal constants, declared constants via *const*, contact expressions via *constexpr*, enumerated constants via *enum*, and defined constants via *#define*.
* Literal constants: 5 (int), 6U (uint), 20L (long), 55LL (long long), -3F (float), 5.5 (double), 10.0L (long double), ‘Z’ (character), “hello” (string), etc.
* Declared constants: *const double pi {3.14159}, const int months\_in\_year {12},* etc.
* Defined constants were used in older code and should be avoided now as it doesn’t support type checking and makes it difficult to debug, e.g. *#define pi 3.14*. The pre-processor replaces any use of the identifier pi with 3.14.
* **Pseudocode** breaks down the algorithm/steps in easy to read English rather than actual code.
* **Escape sequences** are special characters that perform a unique action when output to the console, e.g. *\n* prints a new line, *\t* prints a tab, *\\* prints a \, *\”* prints a “, \’prints a ‘, etc. They are often found in string literals.

Arrays and Vectors

* **Compound data types** are types that are made up of other primitive types.
* **Arrays** contain data in which element is of the same type, are fixed size, and stored contiguously in memory. They are also known as **raw arrays** or **built-in arrays**.
* It’s convenient because a set of data could be contained within a single variable name.
* Once the array size is set, it can’t be changed.
* First index is 0 (zero based index), last index is array\_size – 1. You must ensure that you don’t access an element that’s out of bounds. The program has undefined behaviour and can crash.
* Arrays are normally looped through.
* Array declaration syntax: *int scores [3]* or ‘*const int num = 3; int scores [num]*’ – stores three integers. Note that the size must be defined via a constant.
* There are four ways to initialise arrays:

1) *int scores [5] {}* – all set to 0.

2) *int scores* *[5] {3, 4}* – first two set, rest set to 0.

3) *int scores [5] {5, 3, 4, 2, 1}* – all elements set.

4) *int scores [] {4, 5, 5, 2, 3}* – size automatically calculated.

* Each element can be accessed directly through its index, *e.g. scores[0]* gets first element, *scores[2]* gets third element, etc. *[]* is called the subscript operator.
* The name of the array represents the memory address of the first element. The [index] represents the offset from the first element.
* If you don’t initialise an array and make use of it, you will get undefined output.
* **Multidimensional** arrays represent tables/spreadsheets. To declare them use two square brackets to state number of rows, then columns, etc: e.g. *int movie\_ratings [3][4]*. You access the elements in the same way: e.g.*movie\_ratings[1][2]* returns the integer in the first row in the third column.
* These types of arrays aren’t used frequently in modern C++ as they are error prone. Instead the preference is vectors.
* A **vector** is a dynamic array. It can be resized as required. It’s ideal when you don’t know ahead of time how many elements will be contained within the array.
* The Standard Template Library (STL) has many containers, algorithms, functions, etc. that allow the programmer to focus on the task rather than reinventing code. Vector is defined within the STL. To use it *#include <vector>*.
* Vectors work similarly to built-in arrays, but can provide bounds checking, and has many methods such as sort, reverse, find, etc.
* To declare a *vector* object: *vector <char> vowels*, or *vector <int> test\_scores*, etc. You must specify the element type in the angles brackets as *vector* is a template class.
* To initialise a *vector* object there are multiple ways:

1. *vector <int> scores* – Constructor initialisation. Empty vector, no elements.
2. *vector <int> scores (10)* – Constructor initialisation. All elements set to 0.
3. *vector <int> scores (10, 20)* – Constructor initialisation. 10 elements set to 20.
4. *vector <int> scores {5, 2, 4}* – List initialisation. 3 elements set.

* Vectors are based on built-in arrays so the same logic applies regarding direct indexed access to elements, contiguous in memory, zero based index, etc.
* You can access elements using the subscript operator, but no bounds checking will be done. Use the *at()* method: e.g. *scores.at(1)* vs. *scores[1]*. If you go out of bounds, then the method will throw an exception to indicate this.
* You can add a new element: *scores.push\_back(5)*. This will add 5 to the end of the vector.
* The vector automatically resizes if there isn’t enough space in the vector.
* Call the *size()* method to determine the current size of the vector.
* 2D vector: *vector <vector<int>> ratings {…}*. Element access: *ratings[1][2]* or *ratings.at(1).at(2)* – the first *at()* returns the row, the second *at()* returns a single element.

Statements and Operators

* An **expression** computes a value from a number of operands, e.g. *34, my\_variable, 4 + 5, 2 \* 3, a > b, a = 5,* etc.
* A **statement** is a complete line of code that performs an action. It’s usually terminated with a semi-colon, and usually contains expressions, e.g. *int x; age = 21; 3 + 8; x = 2 \* 3; if (a > b) cout << “a is greater”;* null statement, etc.
* A null statement is just a semi-colon.
* There are unary, binary, and ternary operators that work on 1, 2, or 3 operands.
* Operators can be grouped as: assignment, arithmetic, increment/decrement, relational, logical, member access, etc.
* You can assign multiple variables in a row, the process occurs right to left: *e.g. var1 = var2 = 100*.
* When doing division keep in mind that for an integer variable, the fractional part is dropped.
* The modulus or remainder operation (%) only works with integers.
* The increment and decrement operators just add or minus 1 respectively from the variable, e.g. ‘*int a = 5; a++*’ *a* is now 6. It can be used with integer/floating/pointer types. Don’t overuse the operator and don’t use it more than once within the same statement as it is undefined.
* The increment operator can be applied as prefixes or postfixes. The difference is that prefix first increments, then returns the new value. Postfix returns the value, then increments. The same logic applies to the decrement operator.
* Operations occur on the same type of operands. If one is different then the compiler will attempt to convert it. With differing primitive types in most operations, the smaller type is converted to a larger type, e.g. *int + double = double* as this is a widening conversion and retains data. However, with assignment a narrowing conversion can occur, e.g. *int val = 100.2*, this is *double* to *int*.
* A **type** **cast** is when one type is changed to another. The examples above were implicit casts since the compiler does them. You can tell the compiler what type to convert to using an explicit cast, e.g. *double value = static\_cast<double>(intVariable)*.
* The C-style cast equivalent would have been *double value = (double) intVariable*, however this should be avoided as unlike *static­\_cast*, the C-style cast doesn’t check to see if it’s safe to convert a type. *static\_cast* will error at compile time if the operation is invalid.
* Equality operators include == and !=. They evaluate an expression to *true* (1) or *false* (0). They’re commonly used in control flow statements.
* Boolean expressions are output as 1 or 0 to the console. To change this and output true and false instead, use the *std::boolalpha* stream manipulator.
* Boolean operations can be strange with floating types, i.e. 12.0 == 11.99999999999999999999 may return true. This is because of how floating types are represented in the computer. For this level of precision, you will need to use a specialised library.
* Relational operators include >, >=, <, <=, and <=>. They return *true* if the relationship is true, and *false* if it isn’t, e.g. *5 > 10* returns *false*, *10 >= 10* returns *true*, etc.
* Logical operators include !, &&, and ||. They work with other Boolean types to return a result. ! flips the state, && is only *true* if both operands are, || is true if either operand is. Alternatively, you can use the operators *not, and, or*, but this is not common practice.
* **Short-circuit evaluation** means that compiler stops evaluating the expression as soon as it becomes impossible for it to be anything else: *e.g.* ‘*expr1 && expr2 && expr3*’ stops evaluating the whole expression if a sub-expression is *false*, and ‘*expr1 || expr2 || expr3*’ stops evaluating the whole expression if a sub-expression is *true*.
* **Compound assignment operators** simplify repetitive assignment operations, e.g. *a = a + 5* becomes *a += 5*, *a = a % 3* becomes *a %= 3*, etc. It works with arithmetic and bitwise operators.
* **Operator precedence** refers to the order in which sequential operators are processed. You can use parenthesis in complex expressions to prioritise certain sub-expressions. This works because parenthesis have a high precedence.

Controlling Program Flow

* ***if* statements** allow code to run if a certain condition is met. The expression provided in the bracket must evaluate to *true*, e.g. *if (num < 10) ++num;*.
* To execute more than one statement use a code block, e.g. *if (num < 10) { ++num; cout << “num incrememented.”; }*. The code block has its own scope and can declare other variables local to that block. The variables declared within a block are only visible within that block.
* ***if-else* statement** are similar to an *if* statement, the difference is that if the expression evalues to *false* then code in the *else* block is executed, e.g. *if (num < 10) cout << “num < 10”; else cout << “num >= 10”;*.
* ***if-else if* statements** can check for various conditions from which only the first to evaluate to *true* is executed, the rest are skipped. You can have as many *else if* statements after the *if* statement as required. You can place an *else* block at the end to run some code no matter what. Example:

if (expr1) {

…

} else if (expr2) {

…

} else if (expr3) {

…

} else {

…

}

* **Nested ­*if* statements**check a condition only if another condition has already evaluated to *true*, e.g. *if (expr1) { … if (expr2) {… } … }*.
* **Dangling else** refers to nested *if* statements followed by an *else*block. It’s not clear which *if* statement the *else* block belongs to. In C++ it belongs to the closest *if* statement. It’s recommended to make it explicit by using code blocks. Examples of both:

|  |  |
| --- | --- |
| if (expr1) // Bad: implicit.  if(expr2)  statement1;  else  statement2; | if (expr1) { // Good: explicit.  if(expr2) {  statement1;  } else {  statement2;  }  } |

* ***switch* statements** are very similar to *if* statements, but they check against the value of one constant in a more streamlined syntax. The expression must evaluate to an integral type.
* The *case* statements must contain constant integral expressions. The *break* keyword instructs the compiler to exit the *switch* statement – similar to *if-else if ­*statements. Without the *break* keyword, multiple *case* statements can be run in succession – similar to separate *if* statements.
* The *default* block is similar to an *else* block.
* A *case* statement can have multiple statements without a block, but if a local variable needs to be declared then it must be done within a block.
* The syntax is as follows:

switch (integral\_type) {

case const\_expr1: statement1; break;  
 case const\_expr2: statement2; break;  
 …  
 default: statement\_default;   
}

* Enumeration types are a custom integral type that limit what the type can be assigned to. They also provide more context in the process.
* Example: *int day\_of\_week* could be assigned 1-7 for different days of the week. However, this is prone to error as 1-7 could mean anything and the programmer is not prevented from accidentally typing another number. A better solution is to use an enumerator:

|  |  |
| --- | --- |
| enum DayOfWeek { // Bad: Unscoped  Monday,  Tuesday,  Wednesday,  Thursday,  Friday,  Saturday,  Sunday  }  DayOfWeek day = Monday; | enum class DayOfWeek { // Good: Scoped  Monday,  Tuesday,  Wednesday,  Thursday,  Friday,  Saturday,  Sunday  }  DayOfWeek day = DayOfWeek::Monday; |

It’s good practice to use scoped *enum*s to prevent namespace pollution.

* It works by using integers behind the scenes, Monday is assigned the value 0 by default, Tuesday is 1, etc. You can specify your own values and even repeat them. Since the identifiers are basically constant integers, they can be used in *switch* statements too.
* The conditional operator is a shortcut for short *if-else* statements. It’s a ternary operator that returns one expression or the other, based on the condition. It’s of the form: *(cond\_expr) ? expr\_if\_true : expr\_if\_false*.
* **Looping/iterating** allows executing the same code block repetitively.
* ***for* loops** are used to loop a specific number of times, e.g. *for(int i {0}; i < 5; i++) { … }*.
* The semi-colons are required, but the expressions are all optional. There are three parts to the syntax: initialisation, condition, and increment. The loop initialises local variables, then checks to see if the Boolean condition is true, then executes the loop once. At the end of the loop it increments, then checks to see if the condition is still true before executing the code. It’s conventional to name the loop counter *i*.
* It’s best practice to write loops without missing or complicated expressions.
* **Range-based *for* loops** are used to loop through a collection, e.g. *for(int i : array) { … }*. Can use list initialisation to loop through a range, e.g. *for(int i : {1, 2, 3, 4, 5}) { … }*. You can also provide a string literal as an argument and the loop will go through each character.
* ***while* loops** are used to as long as an expression is true, e.g. *while(is\_true) { … }*. The condition is evaluating initially, and then at the end of every loop. A common mistake is an infinite loop in which the condition never becomes *false* and thus execution never breaks out of the loop.
* ***do-while* loops**are the same as *while* loops, but execute the body at least once, e.g. *do { … } while (expr);*.
* A code block isn’t required if the loop only has a single statement in the body. It’s good practice however to include code blocks regardless as making future changes to code is simpler.
* Variables declared in the loop are local to the loop.
* To loop through an array using a basic *for* loop, provide the loop counter as an argument to the subscript operator for the array.
* Rather than specifying the type yourself, you can make the compiler deduce the type by using the *auto* keyword, e.g. *auto number = 5* – *number* is an *int*.
* The ***continue*** **statement** skips the next iteration of the loop.
* The ***break*** **statement** exits the loop altogether. The *break* statement can be combined with an infinite loop to exit the loop once a condition is met.
* **Nested loops** allow you to loop within a loop, this can be useful when dealing with multidimensional arrays as the outer loop can go through the rows, and the inner loop goes through the columns.

Characters and Strings

Functions

Pointers and References

OOP - Classes and Objects

Operator Overloading

Inheritance

Polymorphism

Smart Pointers

Exception Handling

I/O and Streams

The Standard Template Library (STL)

Bonus Material and Source Code