COMP110: Principles of Computing

Transition to C++ II

Learning outcomes

In this session you will learn how to...

- Split your program into multiple files, and understand the difference between **source files** and **header files**
- Understand the C++ build pipeline, and the roles of the **preprocessor**, **compiler** and **linker**
- Use arrays, and the difference between creating them on the **stack** versus on the **heap**
- Define C++ functions, and how passing **by reference** differs from passing **by value**

Modular program design

Modular program design

- We saw in session 9 that **splitting your code into several files** is generally a good idea
- Python makes it easy: any .py file can be `import`ed on demand
- C++ is a little trickier...

Definitions and declarations

A function **definition** specifies its name, return type, parameters, and the code it contains:

```
double average(double n1, double n2)
{
    return (n1 + n2) / 2.0;
}
```

A function **declaration** specifies everything **except** the code:

```
double average(double n1, double n2);
```

A declaration tells the compiler that this function exists, but is defined **elsewhere**

Sources and headers

- A C++ project contains two main types of file
- **Source files** (.cpp) usually contain **definitions**
- **Header files** (.h) usually contain **declarations**
- For example, `myfile.cpp` may contain some function definitions, and `myfile.h` may contain the declarations for those functions
- (Yep, that means you have to type the same thing twice in two different files...)

Example from last week

words.cpp

```
void readWords()
{
    std::cout << "Reading word list" << std::endl;
    // code omitted
}

std::string chooseRandomWord()
{
    // code omitted
}
```

words.h

```
#pragma once

void readWords();
std::string chooseRandomWord();
```

Example from last week

- `readWords()` and `chooseRandomWord()` are **defined** in `words.cpp`
- `readWords()` and `chooseRandomWord()` are **declared** in `words.h`
- Any file which does `#include "words.h"` can call these functions as if they were declared in that file

How #include works

- **`#include`** works **exactly** as if the **`#include`**d file were copied and pasted at the point where the **`#include`** directive appears
- All header files should start with **`#pragma`** `once` — otherwise, **`#include`**ing the same file more than once will result in duplicate declaration errors
- Putting an **`#include`** directive in the wrong place (e.g. inside a function) will result in weird compile errors

The build process

Executing programs

- CPUs execute **machine code**
- Programs must be **translated** into machine code for execution
- There are three main ways of doing this:
  - An **interpreter** is an application which reads the program source code and executes it directly
  - A **compiler** is an application which converts the program source code into executable machine code
  - A **just-in-time (JIT) compiler** is halfway between the two — it compiles the program on-the-fly at runtime

Examples

Interpreted:

- Python
- Lua
- Bespoke scripting languages

Compiled:

- C
- C++
- Swift

JIT compiled:

- Java
- C#
- JavaScript (in modern web browsers)
- Jython

Interpreter vs compiler

- Run-time efficiency: compiler $>$ interpreter
  - The compiler translates the program **in advance**, on the developer's machine
  - The interpreter translates the program **at runtime**, on the user's machine
- Portability: compiler $<$ interpreter
  - A compiled program can only run on the operating system and CPU architecture it was compiled for
  - An interpreted program can run on any machine, as long as a suitable interpreter is available
- JIT compilers have similar pros/cons to interpreters
- For games, run-time efficiency is usually much more important than portability

The C++ build process

Preprocessor

- Replaces `#include` directives with the contents of the appropriate header files
- Handles other preprocessor directives (`#define`, `#if` etc — more on these another time)

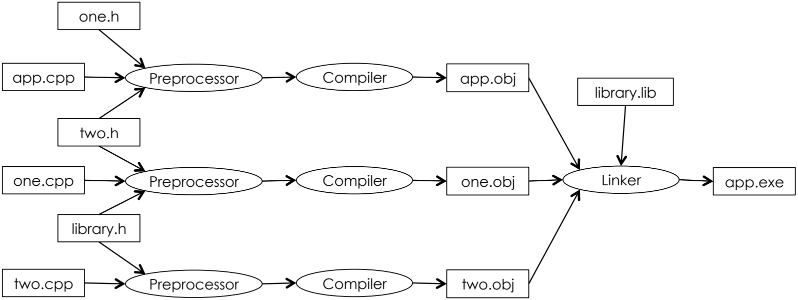
Compiler

- Translates each source file into an **object file** containing machine code

Linker

- Combines the object files together with any external libraries to produce an **executable** (on Windows, a .exe file)

The C++ build process



Modular design revisited

- Your code can call any function for which there is a **declaration** in the current file (in the file itself or `#include`d)
- The **definition** of the function may be in another file
- The **linker** resolves the function call in this case

Incremental compilation

- Compilation can take a long time
- Visual C++ does **incremental compilation**: only recompiles source files that have changed
- Visual C++ uses **precompiled headers**: anything **`#include`**d in `stdafx.h` is only compiled when it changes
- Use **Build** $\rightarrow$ **Clean** or **Build** $\rightarrow$ **Rebuild** to force everything to be recompiled

Build configuration in VC++

- Configuration:
  - **Debug** allows use of the Visual C++ debugger
  - **Release** produces optimised code — usually 2–10 $\times$ faster than Debug
  - Generally use Debug for development, Release for optimisation and distributing the finished application
- Platform:
  - **x86** runs on 32-bit and 64-bit versions of Windows
  - **x64** runs on 64-bit Windows only
  - Generally use x86 for maximum compatibility, x64 for apps which need to use $>$ 2GB memory or where a significant speed benefit is measured

Anatomy of a Visual C++ solution

- A **project** (.vcxproj) is a collection of source files which make up a single application or library
- A **solution** (.sln) is a collection of projects
- The following are intermediate files
  - .sdf files (Visual C++ navigation info)
  - ipch folder (precompiled headers)
  - Debug and Release folders (compiled object code and executables)
- These files can be deleted to save space, and should be in your `.gitignore` file to prevent them being uploaded to GitHub

Arrays and pointers

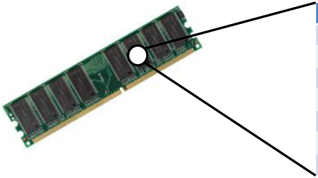
Arrays in C++

- An **array** is a fixed-length sequence of elements of a particular type
- Not to be confused with a **vector**, which is a variable length sequence

```cpp
// Declare a 5-element array with initial values
int myArray[] = { 1, 3, 5, 7, 9 };

// Declare a 10-element array without specifying initial values
int myOtherArray[10];
```

Arrays in memory



Address	Data
00000000	01001000
00000001	01100101
00000002	01101100
00000003	01101100
00000004	01101111
00000005	00100001
...	...

- An array is a contiguous block of memory
- E.g. an **`int`** is 4 bytes (32 bits), so an array of 10 **`int`**s is $10 \times 4 = 40$ bytes
- The size of the array is **fixed**: a 10 element array holds exactly 10 elements, forever

Index out of range

This Python code will give a “list index out of range” exception

```
myList = [1, 3, 5, 7, 9]
print myList[5]
```

This C++ code will give a “vector subscript out of range” exception

```
std::vector<int> myVector = {1, 3, 5, 7, 9};
std::cout << myVector[5] << std::endl;
```

This C++ code will print some arbitrary number

```
int myArray[] = { 1, 3, 5, 7, 9 };
std::cout << myArray[5] << std::endl;
```

Index out of range

- C++ does not check array indices
- It is easy to accidentally read or write past the end of the array, and doing so will cause hard-to-fix bugs
- `myArray` is a 5-element array of **`int`**s, i.e. a block of $5 \times 4 = 20$ bytes
- If `myArray` starts at memory address 1000, then `myArray[i]` is at address $1000 + 4 \times i$
- `myArray[5]` is whatever happens to be at memory address $1000 + 4 \times 5 = 1020$ — could be unallocated memory, could be another variable, could be part of another array, could even be part of the machine code being executed

Array size must be a compile-time constant

```
double a[10];              // OK

const int size = 10;
double b[size];            // OK
double c[2 * size + 7];    // OK

int varSize = 10;
double d[varSize];         // Error
```

Dynamic allocation

- If the size of the array is not known in advance, it can be allocated at runtime using the **`new`** keyword

```
int n = readNumberFromConsole();
int* myArray = new int[n];
```

- Technically `myArray` is no longer an array, it's a **pointer**
- **`int`**`*` is the type "pointer to an **`int`**"
- Pointers can (mostly) be used as if they were arrays

Stack and heap

- Variables and static arrays are stored on the **stack**
  - Stack items are automatically freed when they go out of scope
- Anything created with `new` is stored on the **heap**
  - Heap items must be freed with `delete` when they are finished with
  - Forgetting to free them is a **memory leak**

Strings revisited

- `std::string` is the high-level string class
- The low-level way of storing strings is as an array of **`char`**s

```
char greeting[] = "Hello, world!";
```

- Strings are **null terminated** — they end with ASCII character 0

2-dimensional arrays

Array of arrays approach:

```
const int width = 8, height = 8;
int grid[width][height];
grid[x][y] = 7;
```

Flat array approach:

```
const int width = 8, height = 8;
int grid[width * height];
grid[x + y * width] = 7;
```

Functions

Function definitions

- We have already seen an example of a function definition

```
int main()
{
    std::cout << "Hello, world!" << std::endl;
    return 0;
}
```

- The function `main` takes no parameters, and returns a value of type **`int`**

Function signatures

- The **signature** of a function defines its return type, name, and parameters

```
double foo(std::string x, int y, bool z)
```

- This function takes three parameters:
  - `x` of type `std::string`
  - `y` of type **`int`**
  - `z` of type **`bool`**
- It returns a value of type **`double`**

Functions without return values

- It is possible to define a function which does not return a value, using the **`void`** keyword in place of its return type

```
void printNumber(int n)
{
    std::cout << n << std::endl;
}
```

Pass by value

- Function parameters are passed **by value**: the function receives **copies** of the original variables

```
void changeName(std::string name)
{
    name = "Ed";
}

int main()
{
    std::string name = "Mike";
    std::cout << name << std::endl; // Mike
    changeName();
    std::cout << name << std::endl; // Mike
}
```

Pass by reference

- Parameters can be passed **by reference** using `&`, allowing the function to modify them

```
void changeName(std::string& name)
{
    name = "Ed";
}

int main()
{
    std::string name = "Mike";
    std::cout << name << std::endl; // Mike
    changeName();
    std::cout << name << std::endl; // Ed
}
```

One area where C++ is “simpler” than Python!

- Recall from COMP110 week 6: in Python, basic data types (numbers, booleans, strings etc) are passed by value, and object types (lists, dictionaries, class instances) are passed by reference
- In C++, everything is passed by value unless it is explicitly marked as a reference with `&`

Constant references

```
void greet(std::string name)
{
    std::cout << "Hi " << name << std::endl;
}
```

- The string will be copied in order to be passed in
- More efficient to pass a reference, and mark it **`const`** to prevent accidental modification

```
void greet(const std::string& name)
{
    std::cout << "Hi " << name << std::endl;
}
```

- (this is only worthwhile for large data structures like strings and vectors, not for basic data types)

Live coding: Noughts and Crosses