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**

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

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- **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();
```

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- `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

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- 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

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The build process

Executing programs

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  - 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:

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- Lua
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JIT compiled:

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

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  - 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

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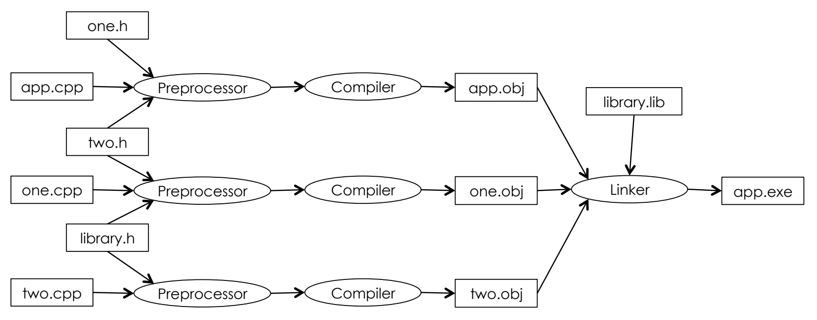
Linker

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

The C++ build process



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- The **linker** resolves the function call in this case

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- Use **Build** → **Clean** or **Build** → **Rebuild** to force everything to be recompiled

Build configuration in VC++

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  - 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

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- 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++

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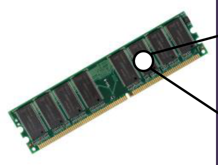
```
// Declare a 5-element array with initial values
int myArray[] = { 1, 3, 5, 7, 9 };

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

Arrays in memory



Address	Data
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...	...

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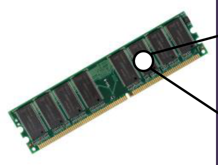

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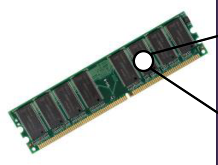

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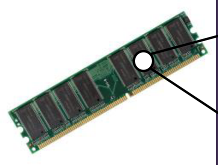

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- An array is a contiguous block of memory
- E.g. an `int` is 4 bytes (32 bits), so an array of 10 `int`s is $10 \times 4 = 40$ bytes
- The size of the array is **fixed**: a 10 element array holds exactly 10 elements, forever

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

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

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std::vector<int> myVector = {1, 3, 5, 7, 9};
std::cout << myVector[5] << std::endl;
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This C++ code will print some arbitrary number

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int myArray[] = { 1, 3, 5, 7, 9 };
std::cout << myArray[5] << std::endl;
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- `myArray` is a 5-element array of `int`s, i.e. a block of $5 \times 4 = 20$ bytes
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- `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

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- `int*` is the type "pointer to an `int`"
- Pointers can (mostly) be used as if they were arrays

Stack and heap

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  - Forgetting to free them is a **memory leak**

Strings revisited

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```
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;
```

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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

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

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

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```
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

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    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

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;
}
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- 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;
}
```

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)

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Live coding: Noughts and Crosses