# 2 - Basic Language Features

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COMP2404

Darryl Hill

# COMP 2404

virtual machines
interpreters
Garbage Collection

# (Short) History of Programming Languages



1. Regional Assembly (1951)
2. FORTRAN (1957)
3. Lisp (1958)
4. COBOL (1959)
5. BASIC (1964)
6. B (1969)
7. Pascal (1970)
8. C (1972)
9. Prolog (1972)
10. Scheme (1975)

# (Short) History of Programming Languages



11. C++ (1980) (C with classes, renamed in 1983)
12. Ada (1983)
13. Objective C (1986, Apple for MacOS and iOS)
14. Perl (1987)
15. Haskell (1990)
16. Python (1990)
17. R (1993)
18. Java (1995)
19. Javascript (1995)
20. PHP (1995)

# Programming Languages



What is the most powerful language?

- the set of problems that are solvable on a computer is the same for all (Turing Complete) languages

- Then what is the difference?
  - Speed
  - Convenience
    - Libraries
  - Compiled vs Interpreted
  - Some are fast, some are expressive, some attempt to do both

C++ has high-level constructs and systems level control

- Ethos - the programmer should not be restricted from doing anything

All programming languages manipulate data

# Data Types



**Data types:**

Primitive

- `int, float, double, char, bool`
- About a constant size (roughly the same as a memory address – more on this later)

Aggregate

- classes - `class Student{ };`
- structs - `struct Student{ };`

Memory address

- pointers - `Student* stu = new Student;`

# Variable and Data Types



All memory looks the same

- 1001001001010111101001101
- Is that a `double, int, char`?
- How does the compiler know?

Memory is pointed to by another piece of memory that has a label that tells the type

- label tells us how to interpret those bits – what value is contained
- `int, double, char`, etc
- This "pointer" memory has an address
- C++ lets us manipulate addresses as well as values

# Variables



Variables have:

- Name
  - How the compiler and programmer identify a variable.
- Type
  - Variable points at a piece of memory with a bit value.
  - Type tells compiler (and programmer) how to interpret that value.
- Address
  - Where in memory the value is stored.
- Value
  - Technically a bit value, but interpreted according to the type

# Memory



In C++ we manage our own memory

- Very important to understand how memory is used
- We will give a basic description here and come back to this model again and again...

Two main places for memory:

**Function call stack**

- Fast, convenient, but temporary

**Heap**

- Slower to allocate but lasts until `delete` is called
- Lifespan must be carefully managed to avoid segfaults and memory leaks

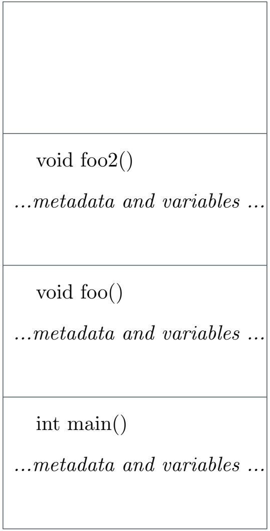
# Function Call Stack



Every time you call a function, a new **Stack Frame** is put on the **Function Call Stack**

- Any local variables are stored in that stack frame
- These variables are deleted automatically when we return from a function

```
void foo2(){
    int x;
}
```



# Heap

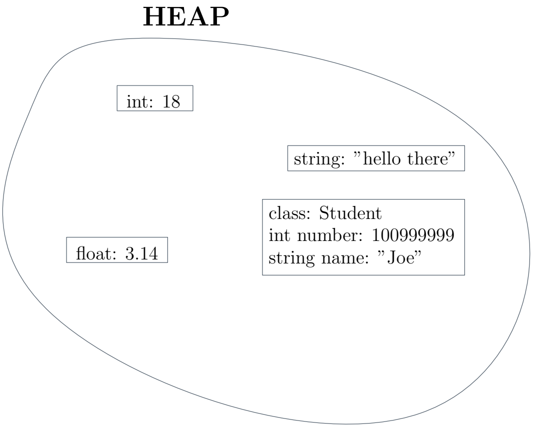
Variable declared with `new` goes on the **Heap**

- `new` keyword returns a pointer
- A pointer contains a memory address

```
int* x = new int;
*x = 18;
```

- must dereference (*) the pointer to access the int value
- variable remains in memory until `delete` is called on the pointer

```
delete x;
```



# Declaring Variables

## Two ways to declare a variable:

Statically allocated

```
int x;
float y;
```

- The variable has memory allocated **where it is declared**
  - could be on the **function call stack** or as data in a **struct** or **class**
  - the containing **struct** or **class** may be **statically** or **dynamically** allocated
  - this variable is deleted automatically

Dynamically allocated

```
int *x = new int;
float *y = new float;
```

- The variable has memory allocated **on the heap**
- deleted when `delete` is called
  - More on `delete` in the **Memory Management** section
  - For now we will focus on creation

# Classes and Structs



## Structs

- In C++ structs have **variables** *and* **functions**
- By default all members are **public**
    - Often (but not always) considered bad software engineering.
- **Do not use *structs* in place of *classes***.
    - You will lose marks.
- ***Structs*** have their place, but we will use ***classes*** almost exclusively.

## Classes

- Contain **variables** and **functions**
- By default all members are **private**
    - (Mostly) considered good software engineering.
    - Prevents misuse or corruption of data.
    - Known as ***the principle of least privilege*** – allow least amount of access to data necessary.

# Operators



We can manipulate data using operators.
They are the usual suspects, and you use them in ways you would expect

Types of operators:

- arithmetic (don't forget BEDMAS!) `+` `-` `*` `/` `%` `++` `--`
- relational (logical, returns `bool`) `==` `<=` `>=` `!=` `<` `>`
- logical (returns `bool`) `&&` `||` `!`
- bitwise `~` `&` `|` `^` `<<` `>>`
- assignment operators `=` `+=` `-=` `*=` `/=` `%=`
- conditional `?` `:` (Like an `if` statement, but returns a value)

**Programming example <p1>**

# Characteristics of Operators



Arity

- the number of arguments
- unary, binary, ternary

Precendence

- The order in which operators execute
- It is not simply left to right – BEDMAS

Associativity

- The order in which operators of the same precedence execute
- left-to-right or right-to-left

# Characteristics of Operators



- Arithmetic operators have left to right associativity
- `a / b / c / d; // the order will affect the outcome`
- Assignment operators have right to left associativity
- `a = b = c = d; // all receive the value in d`
- Prefix vs postfix operators
  - `++x` vs `x++`
- prefix is slightly faster

# C++ Terminology



Putting data and operators together gives us **Expressions**.

Expression:

- A sequence of operations that resolve to a value

```
2 + 2 - 3
3 * variable
2 * pow (5, 3)
2 < 3
```

Expressions are typically embedded into **Statements**

# C++ Terminology



**Statement**

- An instruction or command terminated by a semi-colon
- Can be an expression – return value can be used or discarded
- Can be a function

```
v = 6 + 2;
getValue();
setValue(4);
```

**Programming example <p2>**

# Control Flow Statements



**Statements** can also control the flow of the program.

Conditional

- `if-else`

Selective

- `switch`

Iterative

- `do-while`, `while`, `for`

Jump

- `break`, `continue`

# C++ Terminology



How do statements control the program flow?

By dividing our code into **Blocks**

- been around since 1958 or so
- a sequence of statements between matching braces
  - functions
  - `if` statements, `for-loops`
  - blocks for no reason
- Blocks can have local variables

# Blocks and Local Variables



```
int x = 8;

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

cout<<x<<endl;
```

```
int x = 8;

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

{
    int x = 10;
    cout<<x<<endl;
}

cout<<x<<endl;
```

## Scope

- Block scope
  - declared in a block
  - local to that block
  - "local variables"
- Global scope / file scope
  - declared outside of any block
  - "global variables"
  - we will learn to use them, but should NEVER be used in industrial grade applications

## Programming example <p3>

# Standard I/O Streams



C++ stream library

- `#include <iostream>`
  - allows standard input and output
  - in the `std` namespace
    - same namespace as `strings`
    - more on this later

- `cout` – member of the `ostream` class
  - an object with reference to standard output (console)
  - you can change the output stream associated with `cout` (to a `string` for example)
    - this does NOT change the standard output
    - `printf`, for example, will still print to the screen

# Standard I/O Streams



C++ stream library

```
#include <iostream>
```

- `cin` – member of the `istream` class - standard input – i.e., from the keyboard
- `cerr` – member of the `ostream` class - standard error output (console, or you can set to a log file)

**Programming example <p4>**

# Functions



Methods, subroutines, procedures, etc

- different languages have different names
- functionally (mostly) the same

In C++ there are two kinds of functions

- Global functions
  - belong to everyone
- Member functions
  - Belong to a class (or struct).
  - We will only refer to ***classes*** from now on.

# Functions



Global functions

- C exclusively uses global functions.
- Defined outside of any block (except a namespace).
- Called from any function and any class in the program.
- Example: main().

Member functions

- Java exclusively uses member functions.
- Defined within a class – behaviour of that class.
- Called by an object of that class, however
- static (class) functions can be called on the class itself.

# Functions



Function declaration:

- AKA function prototype or specification.
- Details of ***how*** to call your function.
  - Name, number and types of arguments, return type.
  - Compiler needs only the prototype to determine if you've used function correctly.
- Document your prototype to answer what your function does.
  - Descriptive variables and function names are often best, but when it doubt, provide comments.

# Functions

Function implementation:

- Body of the function.
- Code that executes when the function is called.

Member (and some global) functions in C++:

- Declaration and implementation are stored in different files.
- Header has declaration.
- Source has implementation.

# Functions



(Good) function design:

- Take in parameters (data), process data and return a result using
  - return value, or
  - output parameter(s).
- A function should be single purpose.
  - DON'T try and do everything in one function.
  - DO call another (helper) function if there is more to do.
- Single purpose functions mean:
  - Simple to write.
  - Simple to debug.
  - Simple to document.

# Functions



(Good) function design:

- Encapsulate unnecessary details.
  - Prototypes are often enough for the user.
- Divide large tasks into helper functions.
- Functions should be reusable.
  - Anticipate other uses.
  - Make function as general as possible.

# Functions



(Good) function design - Return values:

- Return values can be used to:
  - Indicate success or failure.
  - As very simple returns, like a getter.
- In C++, results are often returned using output parameters.
  - Can return multiple values.
- **In this class we will practice using output parameters**
- We'll use return values to:
  - Indicate errors.
  - For simple getters.
  - For *cascading* (which we'll see later).

**Return Values** vs **Output Parameters**:

- There are different schools of thought.
  - Not a matter of right and wrong: both can be made to work.
- A matter of performance and safety trade-offs and consistency with the team.
- A developer should know how to use both.

# Function Design



Parameters

- Space is allocated on the function call stack.
  - Same as local variables.

Parameters can be passed in using

- pass-by-value, or
- pass-by-reference.

# Function Design



Pass-by-value:

- The value passed in is copied into a local variable.
  - The value passed in can be a variable or expression.
- The function can only modify the local value - the original value is untouched.

Pass-by-reference:

- The memory address of a variable is ***copied*** and passed into the function.
  - Must be a variable or an expression that evaluates to a variable.
- This address “points” to the original value, allowing us to modify the original value.

# Function Design



In C++, pass-by-reference can be done via ***pointers*** or ***references***.

- There are no references in C, only pointers.

To the compiler ***pointers*** and ***references*** are the same (or exceedingly similar).

- Both are addresses - same memory footprint.
- Use a different syntax.
- More on this shortly.

# Parameter Roles



Input parameter:

- Value or information required by function.
- Sent in by calling function.

Output parameter:

- Result of the function – could be garbage.
- Parameter value is set by the function.

Input / Output parameter:

- A value we want changed by the function.

**programming example <p5>**

# Pass by Reference



Essentially "pass by memory location". Two ways:

- **Pointers:**
  - Powerful.
  - Somewhat natural.
  - Easy to make mistakes with - segmentation fault, or worse, NULL reference (bad memory).
- **References:**
  - Same thing "under the hood" as pointers.
    - It is a memory location.
  - Syntactically treated as a variable.
  - Less versatile than pointers, but easier to use.
  - Supposed to protect against NULL references.
    - But you can do it if you try.

# References



References can also be used outside of parameter passing.

- Must be assigned a memory address to a value on declaration.

```
int x = 10;
int& y = x;
```

- This memory location can never be changed.
  - This reference is permanently BOUND to the memory location of `x`.
  - We call it an ***alias*** for another variable.
    - It is another variable name accessing the same value.
  - The value stored in the memory location that is being pointed to CAN change.
- Most common usage is for passing parameters by reference.

**programming example <p6>**