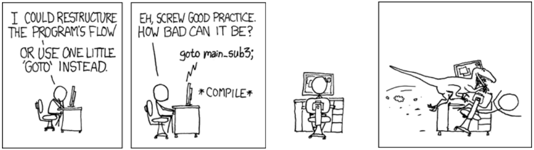
Annotated slides from 4pm class

CS319: Scientific Computing

Getting Started with C++

Dr Niall Madden

Week 2: **9am and 4pm**, 17 January, 2024



Source: xkcd (292)

	Mon	Tue	Wed	Thu	Fri
9 – 10			✓	LAB(?)	
10 – 11					
11 – 12					LAB(?)
12 – 1					LAB(?)
1 – 2					
2 – 3					
3 – 4					
4 – 5			✓		

- My thanks to those who sent me your time-table information.
- Based on that everyone can attend at least two of
  - Thursday 9-10
  - Friday 11-12
  - Friday 12-1.
- First lab is next week (Week 3).
- **Any questions?**

Outline

The C++ topics we'll cover are

1. From Python to C++: input and output, data types and variable declarations, arithmetic, loops, Flow of control (`if` statements), conditionals, and functions.
2. Arrays, pointers, strings, and dynamic memory allocation.
3. File management and data streams.

(Classes and objects will be mentioned in passing).

To get started, we'll use an online C++ compiler. Try one of the following

- `https://www.onlinegdb.com`
- `http://cpp.sh`
- `https://www.programiz.com/cpp-programming/online-compiler/`

Later (once it is properly installed) we can use a C++ compiler and IDE that is installed on the PCs in lab. Most likely, this will be `Code::blocks`.

On your own device, try installing one of the following free IDE's and compilers.

- Windows: `Code::blocks` (install `codeblocks-20.03mingw-setup.exe`)
- Windows: Bloodshed's `Dev-C++`
- maxOs: Xcode
- Linux: it is probably already installed!

The convention is the give C++ programs the suffix *.cpp*, e.g., *hello.cpp*. Other valid extensions are *.C*, *.cc*, *.cxx*, and *.c++*.

If compiling on the command line with, e.g., the GNU Project's C/C++ compiler, the invocation is

```
$ g++ hello.cpp
```

If there is no error in the code, an executable file called `a.out` is created.

The workflow is different with an IDE: we'll demo that as needed.

Most/all of you have some familiarity with Python. There are numerous resources that introduce C++ to Python-proficient programmers.

For example: `https://runestone.academy/ns/books/published/cpp4python/index.html` One of its advantages is that it allows you to try some code in a browser.

Let me know if you find any other useful resource.

Basic program structure

- A "header file" is used to provide an interface to standard libraries. For example, the *`iostream`* header introduces I/O facilities. Every program that we will write will include the line:

  ```
  #include <iostream>
  ```

  > **Python Comparison**
  >
  > This is a *little* like `import` in Python.

- Like Python, the C++ language is case-sensitive. E.g., the functions `main()` and `Main()` are not the same.

Basic program structure

- The heart of the program is the `main()` function – every program needs one. When a compiled C++ program is run, the `main()` function is run first. If it is not there, nothing happens!
- "Curly brackets" are used to delimit a program block.

Python Comparison

This is similar to the use of "*colon and indentation*" in Python.

Example:

Basic program structure

- Every (logical) line is terminated by a semicolon;
  Lines of code not terminated by a semicolon
  are assumed to be continued on the next line;

- Two forward-slashes // indicate a comment – everything after them is ignored until an end-of-line is reached.

Python Comparison

So, this is similar to a # in Python.

This program will output a single line of output:

00hello.cpp

```
#include <iostream>
int main()
{
  std::cout << "Howya World.\n";
  return(0);
}
```

00hello.cpp

```
#include <iostream>
int main()
{
  std::cout << "Howya World.\n";
  return(0);
}
```

- the identifier `cout` is the name of the **Standard Output Stream** – usually the terminal window. In the programme above, it is prefixed by `std::` because it belongs to the *standard namespace*...
- The operator `<<` is the **put to** operator and sends the text to the *Standard Output Stream*.
- As we will see `<<` can be used on several times on one lines. E.g. `std::cout << "Howya World." << std::endl;`

Variables

Variables are used to temporarily store values (numerical, text, etc, ...) and refer to them by name, rather than value.

Unlike Python, all variables must be declared before begin used. Their **scope** is from the point they are declared to the end of the function.

More formally, the variable's name is an example of an **identifier**. It must start with a letter or an underscore, and may contain only letters, digits and underscores.

Examples:

Variables

All variables must be defined before they can be used. That means, we need to tell the compiler the variable's name and **type**.

Every variable should have a **type**; this tells use what sort of value will be stored in it. The type does not change (usually).

Python comparison

In Python, one "declares" a variable just by using it. The type of the variable is automatically determined. Furthermore, its type can change when we change the value stored in the Python variable.
This is one of the reasons why Python is so flexible, and so slow.

Variables

The variables/data types we can define include

- `int`
- `float`
- `double`
- `char`
- `bool`

Variables

Integers (positive or negative whole numbers), e.g.,

```
int i; i=-1;
int j=122;
int k = j+i;
```

← Combining declaration & assignment

← assumes j already has a value.

Floats These are not whole numbers. They usually have a decimal places. E.g,

```
float pi=3.1415;
```

Note that one can initialize (i.e., assign a value to the variable for the first time) at the time of definition. We'll return to the exact definition of a `float` and `double` later.

These declarations can be modified.

Eg `const int j=122;` // j cannot change

Variables

Characters Single alphabetic or numeric symbols, are defined using the `char` keyword:

`char c;` or `char s='7';`

Note that again we can choose to initialize the character at time of definition. Also, the character should be enclosed by single quotes.

Arrays We can declare **arrays** or **vectors** as follows:

```
int Fib[10];
```

This declares a integer array called `Fib`. To access the first element, we refer to `Fib[0]`, to access the second: `Fib[1]`, and to refer to the last entry: `Fib[9]`.

As in Python, all vectors in C++ are indexed from `0`.

Variables

Here is a list of common data types. Size is measured in bytes.

byte = 8 bits, bit is 0 or 1.

Type	Description	(*min*) **Size**
`char`	character	1
`int`	integer	4
`float`	floating point number	4
`double`	16 digit (approx) float	8
`bool`	`true` or `false`	1

See also: `01variables.cpp`

. . . .

In C++ there is a distinction between **declaration** and **assignment**, but they can be combined.

There are other data types – will come back to them as needed.

As noted above, a `char` is a fundamental data type used to store as single character. To store a word, or line of text, we can use either an *array of `chars`*, or a `string`.

If we've included the *`string`* header file, then we can declare one as in: `string message="Well, hello again";` This declares a variable called *`message`* which can contain a string of characters.

03stringhello.cpp

```
#include <iostream>
#include <string>
int main()
{
  std::string message="Well, hello again";
  std::cout << message << std::endl;
  return(0);
}
```

In previous examples, our programmes included the line
`#include <iostream>`
Further more, the objects it defined were global in scope, and not exclusively belonging to the *std* namespace...

A **namespace** is a declarative region that localises the names of identifiers, etc., to avoid name collision. One can include the line
`using namespace std;`
to avoid having to use `std::`

-=-=-=-

It is a little like using
from MODULE import *
rather than
import MODULE

A closer look at `int`

It is important for a course in Scientific Computing that we understand how numbers are stored and represented on a computer.

Your computer stores numbers in binary, that is, in base 2. The easiest examples to consider are integers.

Examples:

Binary	Decimal
0	0
1	1
10	2
11	3
100	4
101	5
110	6
111	7

So, $abcd$ in binary

is $d + 2c + 4b + 8a$
$= d(2^0) + c(2^1) + b(2^2) + a(2^3)$.

Same as in decimal
$wxyz$ in decimal is
$z(10^0) + y(10) + x(10^2) + w(10^3)$.

A closer look at `int`

If we use a single byte to store an integer, then we can represent:

Binary	Decimal
00000000	0
00000001	1
00000010	2.
⋮	
10000000	128
11111111	$255 = 2^8 - 1$

So, we have $2^8 = 256$ different numbers.

A closer look at `int`

In fact, 4 bytes are used to store each `integer`. One of these is used for the sign. Therefore the largest `integer` we can store is $2^{31} - 1$ ...

$= 2 \times 10^9$.

. . . .

We'll return to related types (`unsigned int`, `short int`, and `long int`) later.

A closer look at `float`

C++ (and just about every language you can think of) uses IEEE Standard Floating Point Arithmetic to approximate the real numbers. This short outline, based on Chapter 1 of O'Leary "*Scientific Computing with Case Studies*".

A floating point number ("**float**") is one represented as, say, 1.2345×10^2. The "fixed" point version of this is 123.45.

Other examples:

$$0.01234 = 1.234 \times 10^{-2}$$

Etc.

A closer look at `float`

As with integers, all floats are really represented as binary numbers.

Just like in decimal where ~~3.1425 is~~: 0.03142 is

$$3.142 \times 10^{-2} = (3 \times 10^{0} + 1 \times 10^{-1} + 4 \times 10^{-2} + 2 \times 10^{-3}) \times 10^{-2}$$
$$= 3 \times 10^{-2} + 1 \times 10^{-3} + 4 \times 10^{-4} + 2 \times 10^{-5}$$

For the floating point binary number (for example)

$$1.1001 \times 2^{-2} = (1 \times 2^{0} + 1 \times 2^{-1} + 0 \times 2^{-2} + 0 \times 2^{-3} + 1 \times 2^{-4}) \times 2^{-2}$$
$$= 1 \times 2^{-2} + 1 \times 2^{-3} + 0 \times 2^{-4} + 0 \times 2^{-4} + 1 \times 2^{-6}$$
$$= \frac{1}{4} + \frac{1}{8} + \frac{1}{64} = \frac{25}{16} = 0.390625.$$

But notice that we can choose the exponent so that the representation always starts with 1. That means we don't need to store the 1: it is **implied**.

The format of a float is

$$x = (-1)^{Sign} \times (Significant) \times 2^{(offset+Exponent)},$$

where

- *Sign* is a single bit that determines of the float is positive or negative; Note $(-1)^1 = -1$, $(-1)^0 = 1$
- the *Significant* (also called the "**mantissa**") is the "fractional" part, and determines the precision;
- the *Exponent* determines how large or small the number is, and has a fixed offset (see below).

A `float` is a so-called "single-precision" number, and it is stored using 4 bytes ($= 32$ bits). These 32 bits are allocated as:

- 1 bit for the *Sign*;
- 23 bits for the *Significant* (as well as an leading implied bit); and
- 8 bits for the *Exponent*, which has an offset of $e = -127$.

So this means that we write x as

$$x = \underbrace{(-1)^{Sign}}_{\text{1 bit}} \times 1.\underbrace{abcdefghijklmnopqrstuvw}_{\text{23 bits}} \times \underbrace{2^{-127+Exponent}}_{\text{8 bits}}$$

Since the *Significant* starts with the implied bit, which is always 1, it can never be zero. We need a way to represent zero, so that is done by setting all 32 bits to zero.

A closer look at `float`

The smallest the *Significant* can be is

$$1.\underbrace{0000000000000000000000}_{\text{22 zeros}}1 \approx 1.$$

The largest it can be is

$$1.\underbrace{11111111111111111111111}_{\text{23 ones}} = 2 - 2^{23} \approx 2.$$

A closer look at `float`

The *Exponent* has 8 bits, but since they can't all be zero (as mentioned above), the smallest it can be is $-127+1=-126$. That means the smallest positive float one can represent is
$x=(-1)^0 \times 1.000\cdots 1 \times 2^{-126} \approx 2^{-126} \approx 1.1755 \times 10^{-38}$.

We also need a way to represent ∞ or "Not a number" (`NaN`). That is done by setting all 32 bits to 1. So the largest *Exponent* can be is $-127+254=127$. That means the largest positive float one can represent is
$x=(-1)^0 \times 1.111\cdots 1 \times 2^{127} \approx 2 \times 2^{127} \approx 2^{128} \approx 3.4028 \times 10^{38}$.

A closer look at `float`

As well as working out how small or large a `float` can be, one should also consider how **precise** it can be. That often referred to as the **machine epsilon**, can be thought of as *eps*, where $1 - eps$ is the largest number that is less than 1 (i.e., $1 - eps/2$ would get rounded to 1).

The value of *eps* is determined by the *Significant*.

For a `float`, this is $x = 2^{-23} \approx 1.192 \times 10^{-7}$.

That is (1 == 1-1.0e-8) is true!

As a rule, if `a` and `b` are floats, and we want to check if they have the same value, we don't use `a==b`.

This is because the computations leading to `a` or `b` could easily lead to some round-off error.

So, instead, should only check if they are very "similar" to each other: `abs(a-b) <= 1.0e-6`

A closer look at `float` `double`

For a `double` in C++, 64 bits are used to store numbers:

- 1 bit for the *Sign*;
- 52 bits for the *Significant* (as well as an leading implied bit); and
- 11 bits for the *Exponent*, which has an offset of $e = -1023$.

The smallest positive double that can stored is $2^{-1022} \approx 2.2251e - 308$, and the largest is

$$1.111111\cdots111 \times 2^{2046-1023} = \left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \dots\right) \times 2^{2046-1023}$$
$$\approx 2 \times 2^{1023} \approx 1.7977e + 308.$$

(One might think that, since 11 bits are devoted to the exponent, the largest would be $2^{2048-1023}$. However, that would require all bits to be set to 1, which is reserved for NaN).

For a `double`, machine epsilon is $2^{-53} \approx 1.1102 \times 10^{-16}$.

Finished here 5pm

A closer look at float double

An important example:

03Rounding.cpp

```
int i, n;
float x=0.0, increment;

std::cout << "Enter a (natural) number, n: ";
std::cin >> n;
increment = 1/( (float) n);

for (i=0; i<n; i++)
  x+=increment;

std::cout << "Difference between x and 1: " << x-1
          << std::endl;
```

What this does:

A closer look at `float` `double`

- If we input $n = 8$, we get:
- If we input $n = 10$, we get:

Output Manipulators

As well as passing variable names and strings to the output stream, we can also pass manipulators to change how variable values are displayed. Some manipulators (e.g., `setw`) require that *iomanip* is included.

We've already seen that we can use `std::endl` to print a new line at the end of some output.

04Manipulators.cpp

```
#include <iomanip>
int main()
{
  int i, fib[16];
  fib[0]=1; fib[1]=1;

  std::cout << "Without setw  manipulator" << std::endl;
  for (i=0; i<=12; i++)
  {
    if( i >= 2)
      fib[i] = fib[i-1] + fib[i-2];
    std::cout << "The " << i << "th " <<
      "Fibonacci Number is " <<  fib[i] << std::endl;
  }
```

Output Manipulators

- `std::setw(n)` will the width of a field to *n*. Useful for tabulating data.

04Manipulators.cpp

```
  std::cout << "With the setw  manipulator" << std::endl;
  for (i=0; i<=12; i++)
  {
    if( i >= 2)
      fib[i] = fib[i-1] + fib[i-2];
    std::cout
      << "The " << std::setw(2) << i << "th "
      << "Fibonacci Number is "
      << std::setw(3) <<  fib[i] << std::endl;
```

Other useful manipulators:

- `setfill`
- `setprecision`
- `fixed` and `scientific`
- `dec`, `hex`, `oct`

Input

In C++, the object cin is used to take input from the standard input stream (usually, this is the keyboard). It is a name for the C**onsole** IN**put**.

In conjunction with the operator >> (called the **get from** or **extraction** operator), it assigns data from input stream to the named variable.

(In fact, `cin` is an **object**, with more sophisticated uses/methods than will be shown here).

Input

05Input.cpp

```
#include <iostream>
#include <iomanip> // needed for setprecision
int main()
{
  const double StirlingToEuro=1.16541; // Correct 17/01/2024
  double Stirling;
  std::cout << "Input amount in Stirling: ";
  std::cin >> Stirling;
  std::cout << "That is worth "
            << Stirling*StirlingToEuro << " Euros\n";
  std::cout << "That is worth " << std::fixed
            << std::setprecision(2) << "\u20AC"
            << Stirling*StirlingToEuro << std::endl;
  return(0);
}
```