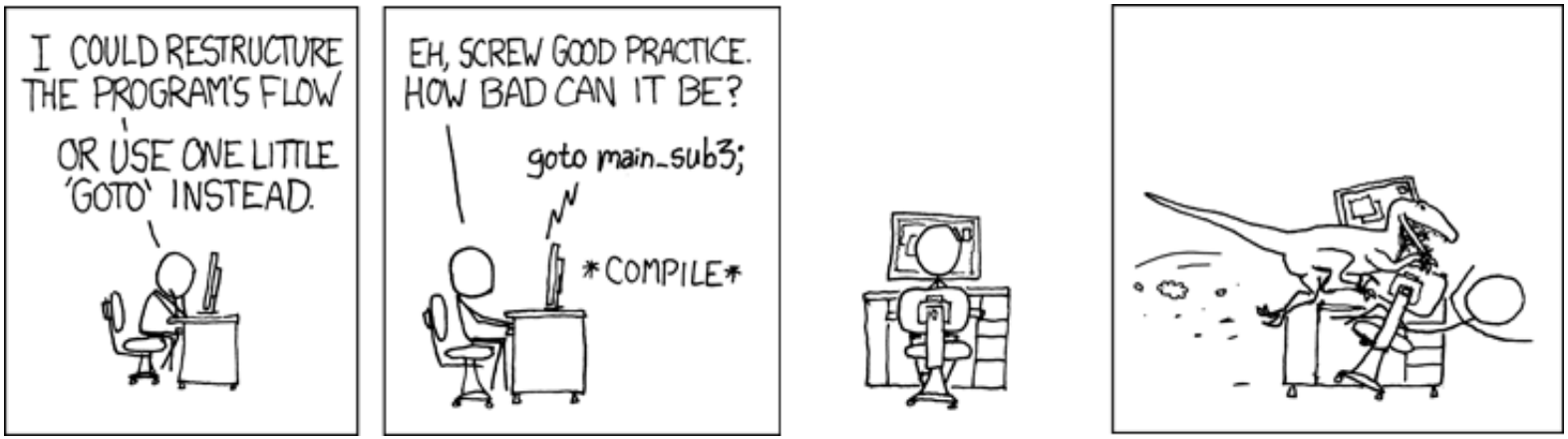
CS319: Scientific Computing (with C++)

http://www.maths.nuigalway.ie/~niall/CS319/

ints and float; input & output; flow; loops; functions

Week 2: **9am and 4pm**, 18 Jan 2017



Source: xkcd (292)

Today:

1. What we learned about C++ last week
2. int: a closer look
3. float: a closer look
   - `double`
4. Output Manipulators
   - endl
   - setw
5. Input
6. Flow of control: `if`-blocks
7. Loops
   - `for` loops
8. Functions
   - E.g, Prime or Composite?
   - `void` functions

What we learned about C++ last week

- A "header file" is used to provide an interface to standard libraries. Every program that we write has the line:
  `#include <iostream>`

- The heart of the program is the `main()` function – every program needs one. `void` is the default argument list and can be omitted.

- The C++ language is case-sensitive.

- "Curly brackets" are used to delimit a program block.

- Every (logical) line is terminated by a semicolon;

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

What we learned about C++ last week

- Use `cout` to send a output to (for example) a terminal window:
  ```
  std::cout << "Howya World." << "\n";
  ```
- All variables must be declared before begin used.

- Each variable has a **type** that determines what sort of value will be stored in it.
- The most basic data types are
  - `int` used to store integers
  - `floats` – numbers that have a fractional (decimal) part.
  - `char` – stores a character (i.e., symbol)

- We can declare **arrays** as follows:
  `int Fib[10];`
  Arrays are indexed from `0`.

- A *`string`* is used to store a sequence of characters. (Not a fundamental data-type — it is actually an object).

What we learned about C++ last week

- The objects defined by
  `#include <iostream>`
  are not truly global in scope, but belong to the *std* namespace.
  A **namespace** is a declarative region that localises the names of identifiers, etc., to avoid name collision. These are then accessed as
  namespace::identifier.
  So, the use the `cout` object provided by *iostream*, and which belongs to the *std* namespace, refer to it as
  `std::cout`
- If one wants to avoid having to refer to the namespace, you can use the *using* key-word. Example: if you code includes `using namespace std`; then referring directly to `cout` is the same as `std::cout`.

. . . . . .

The use of "using" is not regarded as good programming practice..

int: a closer look

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 `int`egers.

Examples:

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

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

. . . . . .

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

float: a closer look

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*". The format of a float is $x = (-1)^{Sign} \times (Significant) \times 2^{Exponent}$ where

- *Sign* is a single bit that determines of the float is positive or negative;
- 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 an offset, rather than a sign bit (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 $e = -127$.

float: a closer look

So this means that we write x as

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

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.
Thus, the smallest the *Significant* can be is $1.\underbrace{00000000000000000000}_{22\text{ zeros}}1 \approx 1$.

The largest it can be is $1.\underbrace{11111111111111111111}_{23\text{ ones}} = 2 - 2^{-23} \approx 2$.

Here it helps to remember that the binary faction 1.1 means (in decimal) $1 + \frac{1}{2}$, 1.11 means $1 + \frac{1}{2} + \frac{1}{4}$, etc.

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
$x = (-1)^0 \times 1.000\cdots1 \times 2^{-126} \approx 2^{-126} \approx 1.1755e-38$.

float: a closer look

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 $x = (-1)^0 \times 1.111\cdots1 \times 2^{127} \approx 2 \times 2^{127} \approx 2^{128} \approx 3.4028e + 38$.

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 $x = 2^{-23} \approx 1.192 \times 10^{-7}$.

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

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

(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 $2^{-53} \approx 1.1102 \times 10^{-16}$.

An important example:

Week02/01Rounding.cpp ← link!

```
int i, max;
float x, increment;

cout << "Enter a (natural) number, n: ";
cin >> max;
x=0.0;
increment = 1/( (float) max);

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

std::cout << "Difference between x and 1 is " << x-1 << "\n";
```

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

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.

- `endl` print a new line (and flush)

02Manipulators.cpp

```
10 #include <iomanip>

12 int main()
   {
14   int i, fib[16];
     fib[0]=1; fib[1]=1;

     cout << "\n\nWithout the setw  manipulator" << endl;
18   for (i=0; i<=12; i++)
     {
20     if( i >= 2)    fib[i] = fib[i-1] + fib[i-2];
       cout << "The " << i << "th " <<
22       "Fibonacci Number is " <<  fib[i] << endl;
     }
```

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

02Manipulators.cpp

```
24  cout << "\n\nWith the setw  manipulator" << endl;
    for (i=0; i<=12; i++)
26  {
      if( i >= 2)    fib[i] = fib[i-1] + fib[i-2];
28    cout << "The " << setw(2) << i << "th " <<
       "Fibonacci Number is " << setw(3) << fib[i] << endl;
30  }
    return(0);
32  }
```

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.

(Later we will see that `cin` is an **object**, with more sophisticated uses/methods than is going to be shown here. However, we will defer this discussion until we have studied something of **objects** and **classes**).

Input

03Input.cpp

```
 6 #include <iostream>
   #include <iomanip> // needed for setprecision

   using namespace std;

   int main()
12 {
     const double StirlingToEuro=1.15735; // Correct 17/01/17
14   double Stirling;
     cout << "Input amount in Stirling: ";
16   cin >> Stirling;
     cout << "That is worth " << Stirling*StirlingToEuro << " Euros\n";
18   cout << "That is worth " << fixed << setprecision(2) <<
        "\u20AC" << Stirling*StirlingToEuro << endl;
20   return(0);
   }
```

Flow of control: `if`-blocks

`if` statements are used to conditionally execute part of your code.

Structure (i):

```
if( exprn )
{
  statements to execute if exprn evaluates as
               non-zero
}
else
{
   statements if exprn evaluates as 0
}
```

Flow of control: `if`-blocks

The argument to `if()` is a **logical expression**.

Example

- `x == 8`
- `m == '5'`
- `y <= 1`
- `y != x`
- `y > 0`

More complicated examples can be constructed using **AND** `&&` and **OR** `||`.

Flow of control: `if`-blocks

04EvenOdd.cpp

```
#include <iostream>

int main(void)
{
  int Number;

  std::cout << "Please enter an integrer: ";
  std::cin >> Number;

  if ( (Number%2) == 0)
    std::cout <<  "That is an even number." << std::endl;
  else
    std::cout <<  "That number is odd." << std::endl;

  return(0);
}
```

Flow of control: `if`-blocks

More complicated examples are possible:

Structure (ii):

```
if( exp1 )
{
    statements to execute if exp1 is "true"
}
else if (exp2)
{
    statements run if exp1 is "false" but exp2 is "true"
}
else
{
    "catch all" statements if neither exp1 or exp2 true.
}
```

Flow of control: if-blocks

05Grades.cpp

```
10 int main(void)
   {
12    int NumberGrade;
      char LetterGrade;

      std::cout << "Please enter the grade (percentage): ";
16    std::cin >> NumberGrade;

18    if ( NumberGrade >= 70 )
         LetterGrade = 'A';
20    else if ( NumberGrade >= 60 )
         LetterGrade = 'B';
22    else if ( NumberGrade >= 50 )
         LetterGrade = 'C';
24    else if ( NumberGrade >= 40 )
         LetterGrade = 'D';
26    else
         LetterGrade = 'E';

      std::cout << "A score of " << NumberGrade << "% cooresponds to a "
30             << LetterGrade << "." << std::endl;

32   return(0);
   }
```

Flow of control: `if`-blocks

The other main flow-of-control structures are the

- `switch ... case` structures
- the use of the `?` and `:` operators.

Exercise 2.1

- Find out how `switch.. case` works. Rewrite the Even/Odd example above using `switch ... case`.
- What errors/bugs/problems are there with the `Grades` example? That is, how could you get it to break?
- Read up on the *`switch / case`* construct. Can it be used to write an improved version of the programme. (Hint: yes, but you need a recent C++ compiler...).

We meet a `for`-loop briefly in the Fibonacci example. The most commonly used loop structure is `for`

```
for(initial value; test condition; step)
{
    // code to execute inside loop
}
```

Example: `06CountDown.cpp`

```
10 int main(void)
   {
12   int i;

14   for (i=10; i>=1; i--)
       std::cout << i << "... ";

     std::cout << "Zero!\n";

     return(0);
20 }
```

The other two common forms of loop in C++ are

- `while` loops
- `do ... while` loops

Exercise 2.2

Rewrite the **count down** example above using a

1. `while` loop.
2. `do ... while` loop.

Functions

A good understanding of **functions**, and their uses, is of prime importance.

Some functions return/compute a single value. However, many important functions return more than one value, or modify one of its own arguments.

For that reason, we need to understand the difference between **call-by-value** and **call-by-reference** (⟵ next week).

Every C++ program has at least one function: `main()`

Example

```
#include <iostream>

int main(void )
{
   /* Stuff goes here */
   return(0);
}
```

Functions

Each function consists of two main parts:

- Function "header" or **prototype** which gives the function's
  - return value data type, or `void` if there is none, and
  - parameter list data types or `void` if there are none.

  The prototype is often given near the start of the file, before the **main()** section.

  Important: The prototype should be written before the function—perhaps when the program is begin specified.
- **Function definition**. Begins with the function names, parameter list and return type, followed by the body of the function contained within curly brackets.

Functions

Format:

```
ReturnType FnName ( param1, param2, ...)
{
      statements
}
```

- `ReturnType` is the data type of the data returned by the function.
- `FnName` the identifier by which the function is called.
- `Param1, ...` consists of
  - the data type of the parameter
  - the name of the parameter will have in the function. It acts within the function as a local variable.
- the statements that form the function's body, contained with braces `{...}`.

07IsComposite.cpp

```
30 int IsComposite(int i)
   {
32   int k;

34   for (k=2; k<i; k++)
       if ( (i%k) == 0)
36       return(k);

38   // If we get to here, then i has no divisors between 2 and i-1
     return(0);
40 }
```

Calling the `IsComposite` function:

07IsComposite.cpp

```
12 int main(void )
   {
14   int i;

16   std::cout << "Enter a natural number: ";
     std::cin >> i;

     if (IsComposite(i))
20     std::cout << i << " is a composite number." << std::endl;
     else
22     std::cout << i << " is a prime number." << std::endl;

24   return(0);
   }
```

Most functions will return some value. In rare situations, they don't, and so have a `void` argument list.

08Kth.cpp

```
#include <iostream>

void Kth(int i);

int main(void )
{
  int i;

  std::cout << "Enter a natural number: ";
  std::cin >> i;

  std::cout << "That is the ";
  Kth(i);
  std::cout << " number." << std::endl;

  return(0);
}
```

08Kth.cpp (continued)

```
26 // FUNCTION KTH
   // ARGUMENT: single integer
28 // RETURN VALUE: void (does not return a value)
   // WHAT: if input is 1, displays 1st, if input is 2, displays 2nd,
30 // etc.
   void  Kth(int i)
32 {
     std::cout << i;
34   i = i%100;
     if ( ((i%10) == 1) && (i != 11))
36     std::cout << "st";
     else if ( ((i%10) == 2) && (i != 12))
38     std::cout << "nd";
     else if ( ((i%10) == 3) && (i != 13))
40     std::cout << "rd";
     else
42     std::cout << "th";
   }
```