

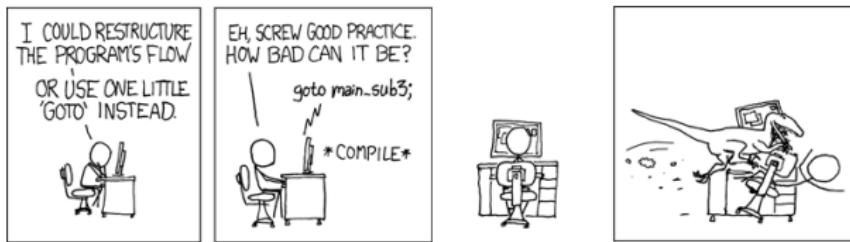
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## CS319: Scientific Computing

# Data types in C++

Dr Niall Madden

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Source: [xkcd \(292\)](#)

	Mon	Tue	Wed	Thu	Fri
9 – 10			X	Lab	
10 – 11					
11 – 12					Lecture
12 – 1					Lab
1 – 2					
2 – 3					
3 – 4					
4 – 5			Lecture		

Confirmed: Labs start next week. We'll have sessions Thursday at 9 and Friday at 12: attend either one (or both!).

- 1 Variables
- 2 Types
  - Strings
  - Header files and Namespaces
- 3 A closer look at int
- 4 A closer look at float
  - Binary floats
- Comparing floats
- double
- Summary
- 5 Basic Output
- 6 Output Manipulators
  - endl
  - setw
- 7 Input

# 1. Reminder: Programming Platform

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

- ▶ <http://cpp.sh>
- ▶ <https://www.programiz.com/cpp-programming/online-compiler/>
- ▶ <https://www.onlinegdb.com> (seems not to be working at the moment...)

If using a PC in the lab, try [Code::blocks](#).

You should also install a compiler and IDE on your own device.

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**Update:** [code::blocks](#) is back online; new version [\*codeblocks-25.03mingw-setup.exe\*](#) now available.

## 2. Variables

The next few slides are modified from those presented Wednesday. Sorry!!!

**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 being used. Their **scope** is from the point they are declared to the end of code block in which they are defined.  
(Recall: code blocks start with { and end with }).

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 of valid identifiers:** var\_name, \_abs, AbCD, x, p123d

**Examples of invalid identifiers:** 3val (since it starts with a digit), var name (has a space)

## 2. 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.

The variables/data types we can define include **int**, **float**, **double**, **char**, and **bool**.

### 3. Types

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

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

### 3. Types

**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.

**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.

### 3. Types

Arrays These are **lists** of variables, but all of the same type.

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.

### 3. Types

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

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: [00variables.cpp](#)

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

As noted above, a `char` is a fundamental data type used to store a 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.

01stringhello.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*::

(The C++ world is a little divided on whether `using namespace std` is good or bad practice. Personally, I don't use it, because it can impact the portability of my code. Only exception is that sometimes it helps fit my code examples onto a slide!)

## 4. 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:**

## 4. A closer look at int

If just **one** byte were used to store an integer, then we could represent:

## 4. 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  $2^{31} - 1$  ...

.....

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

## 5. 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,  $1.2345 \times 10^2$ . The "fixed" point version of this is 123.45.

Other examples:

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

Just like in decimal where 0.03142 is:

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

For the floating point binary number (for example)

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

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

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

where

- ▶ *Sign* is a single bit that determines if 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 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

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

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.

The smallest the *Significant* can be is

$$1.\underbrace{00000000000000000000000}_{22 \text{ zeros}}1 \approx 1.$$

The largest it can be is

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

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

$$x = (-1)^0 \times 1.000\cdots1 \times 2^{-126} \approx 2^{-126} \approx 1.1755 \times 10^{-38}.$$

We also need a way to represent  $\infty$  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

$$x = (-1)^0 \times 1.111\cdots1 \times 2^{127} \approx 2 \times 2^{127} \approx 2^{128} \approx 3.4028 \times 10^{38}.$$

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  $1 - \text{eps}$  is the largest number that is less than `1` (i.e.,  $1 - \text{eps}/2$  would get rounded to `1`).

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

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

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`

## 5. 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

$$1.111111\cdots 111 \times 2^{2046-1023} = \left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \dots\right) \times 2^{2046-1023}$$
$$\approx 2 \times 2^{1023} \approx 1.7977e + 308.$$

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

## 5. A closer look at float

double

An important example:

02Rounding.cpp

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

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

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

19   std::cout << "Difference between x and 1: " << x-1
20     << std::endl;
21   return(0);
```

What this does:

### Examples:

We now know...

- ▶ An `int` is a whole number, stored in 32 bytes. It is in the range  $-2,147,483,648$  to  $2,147,483,647$ .
- ▶ A `float` is a number with a fractional part, and is also stored in 32 bits.  
A positive `float` is in the range  $1.1755 \times 10^{-38}$  to  $3.4028 \times 10^{38}$ .  
Its **machine epsilon** is  $2^{-23} \approx 1.192 \times 10^{-7}$ .
- ▶ A `double` is also number with a fractional part, but is stored in 64 bits.  
A positive `double` is in the range  $2.2251 \times 10^{-308}$  to  $31.7977 \times 10^{308}$ .  
Its **machine epsilon** is  $2^{-53} \approx 1.1102 \times 10^{-16}$ .

## 6. Basic Output

Last week we had this example: *To output a line of text in C++:*

```
#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." << "\n";
```

## 7. Output Manipulators

endl

As well as passing variable names and string literals to the output stream, we can also pass **manipulators** to change how the output is displayed.

For example, we can use `std::endl` to print a new line at the end of some output.

In the following example, we'll display some Fibonacci numbers.

Note that this uses the `for` construct, which we have not yet seen before. It will be explained next week

## 03Manipulators.cpp

```
4 #include <iostream>
5 #include <string>
6 #include <iomanip>
7 int main()
8 {
9     int i, fib[16];
10    fib[0]=1; fib[1]=1;
11
12    std::cout << "Without setw manipulator" << std::endl;
13    for (i=0; i<=12; i++)
14    {
15        if( i >= 2)
16            fib[i] = fib[i-1] + fib[i-2];
17        std::cout << "The " << i << "th " <<
18        "Fibonacci Number is " << fib[i] << std::endl;
19    }
```

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

## 03Manipulators.cpp

```
22 std::cout << "With the setw  manipulator" << std::endl;
23 for (i=0; i<=12; i++)
24 {
25     if( i >= 2)
26         fib[i] = fib[i-1] + fib[i-2];
27     std::cout
28         << "The " << std::setw(2) << i << "th "
29         << "Fibonacci Number is "
30         << std::setw(3) <<  fib[i] << std::endl;
```

Other useful manipulators:

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

## 8. 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 **Console INput**.

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).

## 8. Input

### 04Input.cpp

```
4 #include <iostream>
5 #include <iomanip> // needed for setprecision
6 int main()
7 {
8     const double StirlingToEuro=1.16541; // Correct 17/01/2024
9     double Stirling;
10    std::cout << "Input amount in Stirling: ";
11    std::cin >> Stirling;
12    std::cout << "That is worth "
13        << Stirling*StirlingToEuro << " Euros\n";
14    std::cout << "That is worth " << std::fixed
15        << std::setprecision(2) << "\u20AC"
16        << Stirling*StirlingToEuro << std::endl;
17    return(0);
18 }
```