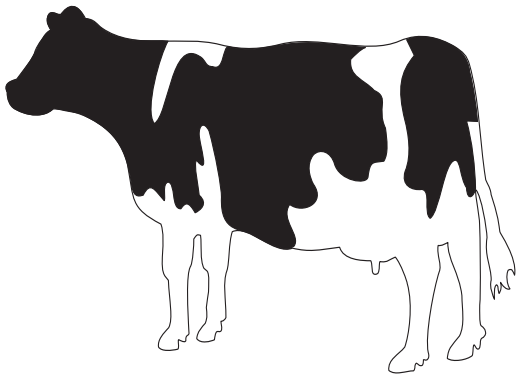
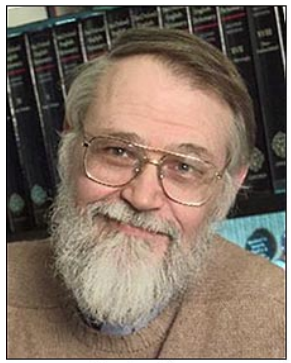
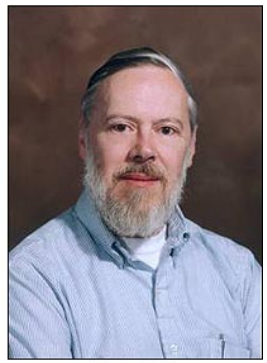
Week 2: Introduction to Programming in C
CS211: Programming and Operating Systems

Niall Madden

Wednesday and Thursday, 22+23 Jan, 2020




Brian Kernighan


Dennis Ritchie

Reminders CS211

Lecturer: Dr Niall Madden, School Mathematics, Statistics and Applied Mathematics (he/him).

Where I am: Office: AdB-1013, Arás de Brún.

Contact me: Email: Niall.Madden@NUIGalway.ie
Always include "CS211" in the subject line of your message

Lectures

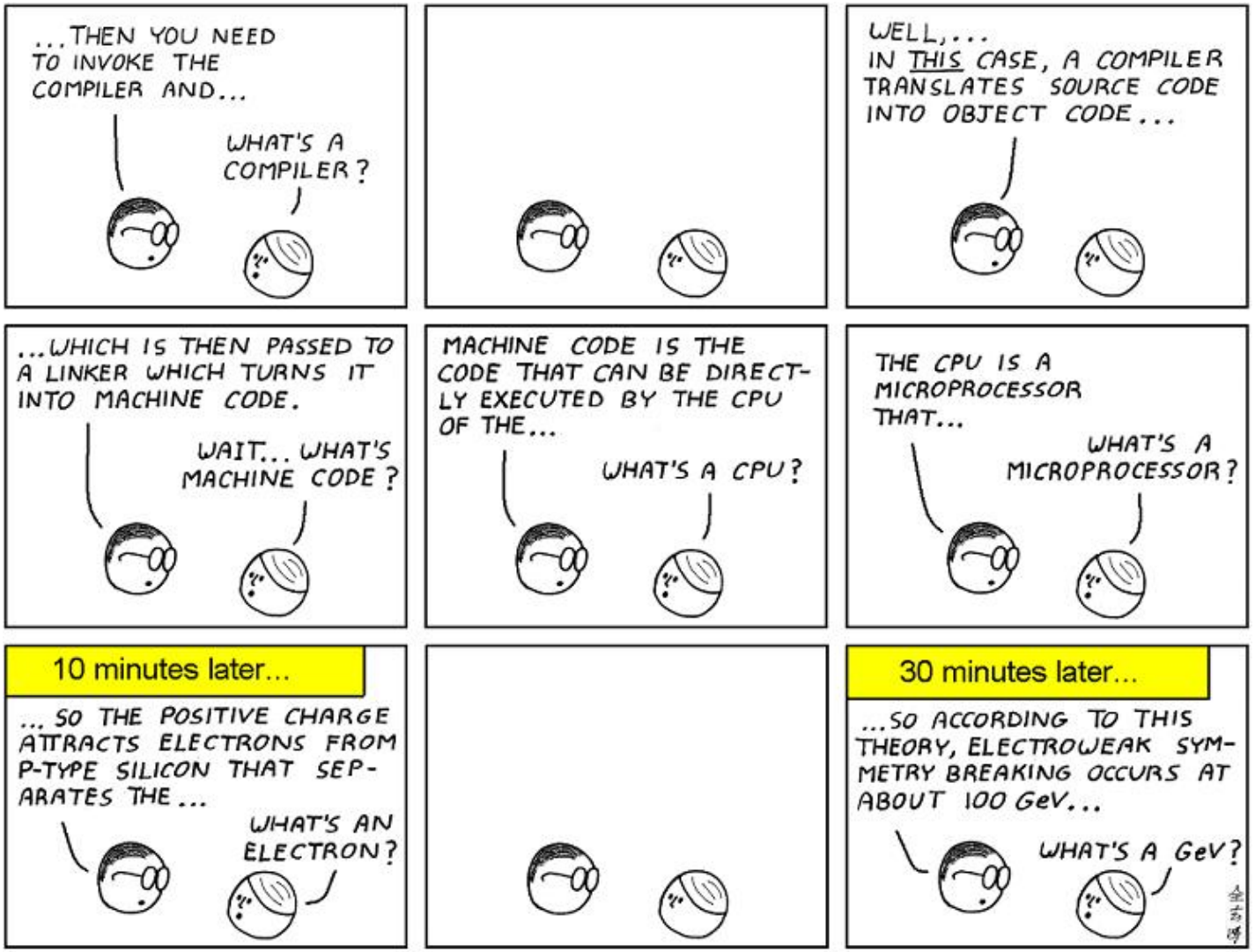
Lecture	Wednesday	15:00–15:50	AC202
Lecture	Thursday	13:00–13:50	AC204
Lab	???	???	???

Computer labs are a very important part of this course, and attendance is considered mandatory

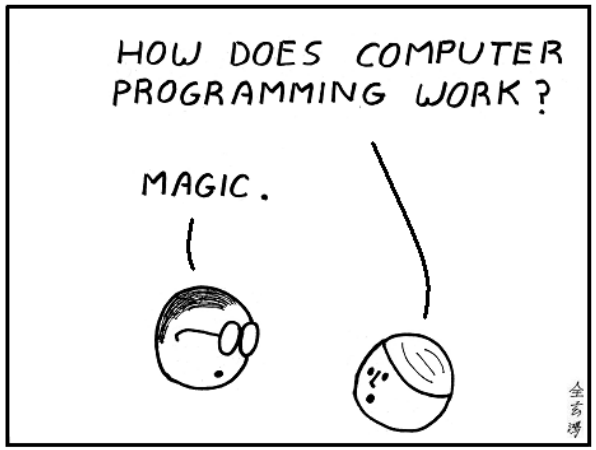
First lab: next week.

What is a compiler?

Abstruse Goose 98: Computer Programming 101



This week's classes



Abstruse Goose: under the hood

The first version of the UNIX operating system (from which many/most other modern systems evolved, including MacOS and GNU/Linux) was developed at Bell Labs in 1969 for a DEC PDP-7. It was written in assembly language.

It became apparent that to develop the operating system further, it would have to be rewritten in a high level language. There wasn't one available, so they wrote one: in 1972/73 the first C compiler was written.

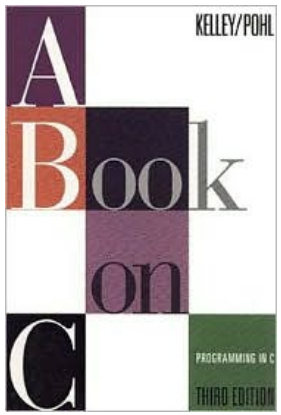
It's main goals were

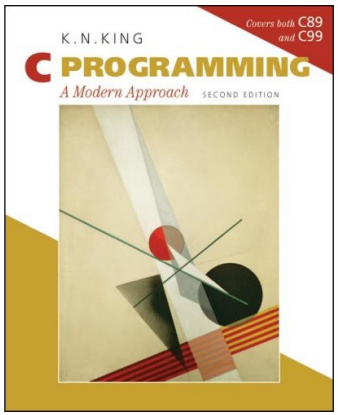
- to be suitable for developing operating systems,
- be portable: compilers should be available for different computers.

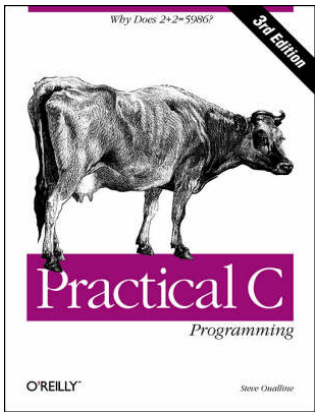
The C language has continued to be developed and refined, with the most recent standard was released in 2011.

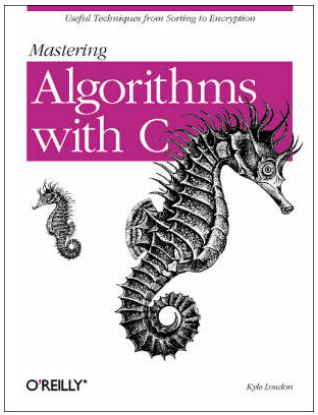
Many other languages are derived from C, or borrow heavily from its syntax, notably C++, Java, C#, PHP, Objective-C, Perl, Javascript.

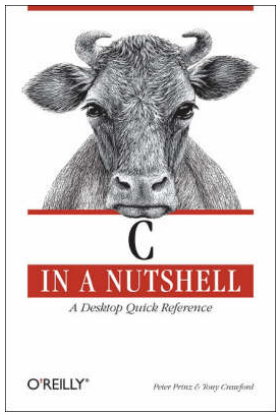
Get a good book on C. It doesn't really matter which book! I like











These are all in the library, and "Practical C" is available online at no cost to you, through the library.

If you find some useful resource for learning C, please let me know, so that I can share with the rest of the class.

You'll also need some software to support your programming, usually:

- an IDE in which you write code;
- a **compiler** to make your code executable.

You can install these on your own computer. If doing so, I suggest `Code::Block`: `http://www.codeblocks.org/`, which is free and comprehensive (though some of the lab work we will do is OS-dependent).

Mainly, however, we will use some excellent online editors and compilers. I suggest

- `https://www.onlinegdb.com/online_c_compiler`
- `http://cpp.sh/`
- `https://www.codechef.com/ide`
- `www.tutorialspoint.com/compile_c_online.php`

Course Content

In order to explore how operating systems work, you'll need to a good basic grasp of C. The basic components that we'll study are

1. Fundamentals of C, including
   - program structure
   - data types and variable declarations,
   - input/output,
   - arithmetic,
   - loops,
   - Flow of control (`if` statements), conditionals,
2. Functions.
3. File management and data streams.
4. Arrays, **pointers** and strings.
5. Dynamic memory management.
6. Abstract data types: Structures and Unions.

Course Content

For the next two weeks we'll cover the fundamentals:

(i) Basic programming structure
(ii) Variables
(iii) Arithmetic
(iv) Basic output
(v) `for` loops
(vi) Basic input
(vii) `if` blocks
(viii) functions.

Course Content

Some important points about C:

- It is a ***compiled*** language, not an interpretive one. This means that we need a program, called the **compiler** to covert our human-readable source code into something our computer can interpret.
- It is a very **small** language; and relies heavily on external libraries that contain **function**s to achieve many important tasks, including input and output.
- But the compiler has to be told in advance how these functions should be used. So before the compilation process, the **preprocessor** is run to `include` the function descriptions that the programmer thinks are necessary.
- The code is then compiled into machine instructions (***object code***).
- The object code is ***linked*** with library functions to produce executable code.

01Hello.c ← link!

```
1 #include <stdio.h>
  int main(void )
3 {
      printf("Hello, World!\n");
5     return(0);
  }
```

Line 1: The first line begins with a # symbol. This is a "preprocessor directive".

It directs the compiler to include a header file (a.k.a., "dot h file") called `stdio.h`.

`stdio.h` is the **st**andar**d** **I**nput/**O**utput **h**eader file. It contains important information about the function `printf()`.

The angle brackets $<$ and $>$ means that the preprocessor should look in the "usual place" (varies between installations).

01Hello.c ← link!

```
#include <stdio.h>
int main(void )
{
    printf("Hello, World!\n");
    return(0);
}
```

Line 2: In C, almost everything is either

1. a preprocessor directive.
2. a variable, or variable declaration.
3. **a function**

The example is no different. Essentially, it is just a definition of the fundamental function `main()`. Here (and often), the function `main()` does not take any arguments, but returns an integer.

C is **case sensitive**, so `main` is different from `Main` is different from `MAIN`, etc.

01Hello.c ← link!

```
#include <stdio.h>
int main(void )
{
    printf("Hello, World!\n");
    return(0);
}
```

Lines 3 and 6: The definition of the `main()` function is encapsulated by "curly brackets": { and }

In C these are used to delimit various types of programme blocks.

01Hello.c ← link!

```
#include <stdio.h>
int main(void )
{
    printf("Hello, World!\n");
    return(0);
}
```

Line 4: The function `printf()` is used to send output to `stdout`. Everything between quotes is displayed. The `\n` is a "new line". These are not printed by default, so Line 4 above is equivalent to

```
    printf("World!");  printf("\n");
```

More about *printf* later....

Note that each (logical) line within a function is terminated by a semicolon.

01Hello.c ← link!

```
1 #include <stdio.h>
  int main(void )
3 {
      printf("Hello, World!\n");
5     return(0);
  }
```

Line 5: The `return` keyword specifies what value should be returned to the function that called it.

Here `main` is called by the Operating System, so in this instance it specifies what the program returns to the OS on exit.

The value `0` (zero) means “everything is OK”.

Any good program should have some documentation to explain to others

- why, when and by who it was written,
- how it works.

In C, there are two types of comments:

1. **block comments**; Starts with `/*` and ends with `*/`. Everything in between, including new lines, are ignored.
2. **single line comments**; Everything after `//` is ignored.

It is important to add comments to you code: your future self with thank you. But, where possible, make the code self-commenting, by using sensible names for identifiers.

Variables

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

All variables must be defined before they can be used. That means, we need to tell the compiler before we use them.

Every variable should have a **type**; this tells use what sort of value will be stored in it.

The variables/data types we can define include

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

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

  Note that one can initialize (i.e., assign a value to the variable for the first time) at the time of definition.

Variables

- Floats – these are not whole numbers. They usually have a decimal places. E.g,

  ```
  float pi=3.1415;
  ```

- 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.

- 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]`.

- Note that in `C`, all vectors are indexed from `0`.

In C, a variable (or function) name can be made up of up to 52 characters long and include

- *Alphabetic characters*: `A`, `B`, ..., `Z`, `a`, `b`, ..., `z`
- *Numeric characters*: `0`, `1`, ..., `9`
- The underscore symbol: `_`

However,

- it must start with a letter or underscore.
- it cannot be a keyword (e.g., `for`, `if`, `return`).

To display the value stored in a variable, we use *printf*

02Variables.c

```
    int k=-101;
12  float f=1.23456;
    char c='a';
14  printf("Values of f, k, c are: %f, %d, %c\n",
            f, k ,c );
```

Explanation:

In this example, we use an **array**

Example (Using `printf`)

```
#include <stdio.h>
int main(void )
{
  int Fib[3];
  Fib[0]=1; Fib[1]=1;

  Fib[2]=Fib[0]+Fib[1];
  printf("Fib[2] = %d\n", Fib[2]);
  return(0);
}
```

Explanation:

- To print a line of text: `printf("Hello world");`
- To print some text followed by a new line:
  `printf("Hello world\n");`
  Here `\n` is an example of an "escape character". Others include `\t` for a horizontal tab and `\a` for an "alert", i.e., a beep.
- `%d` is a ***conversion character***. It means "treat the next variable as an integer". Other important ones include: `%c` (a character), `%f` (a float), `%s` (a sting – i.e., and array of characters).

Keywords

In has a set of reserved keywords; they cannot be used as variable or function names:

`auto`	`double`	`int`	`struct`
`break`	`else`	`long`	`switch`
`case`	`enum`	`register`	`typedef`
`char`	`extern`	`return`	`union`
`const`	`float`	`short`	`unsigned`
`continue`	`for`	`signed`	`void`
`default`	`goto`	`sizeof`	`volatile`
`do`	`if`	`static`	`while`

Some “new” ones, which may be supported by old compilers, include

`restrict` `_Bool` `_Complex` `_Imaginary`

Operators come in **four** flavours: ***Arithmetic***, ***assignment*** ***relational*** and ***logical***.

Arithmetic Operators available in C include:

Symbol	Definition	Example
+	addition	`c = a + b;`
-	subtraction	`c = a - b;`
*	multiplication	`c = a * b;`
/	division	`c = a / b;`
%	remainder	`c = a % b;`

Unlike Python, there isn't a built-in function for powers or truncating division.

The Assignment and Arithmetic-Assignment Operators are:

Symbol	Definition	Example
=	assignment	`a=b;`
++	increment	`a++;`
--	decrement	`a--;`
+=	increment and assign	`a+=2;`
-=	decrement and assign	`a-=2;`
*=	multiply and assign	`a*=2;`
/=	divide and assign	`a/=2;`
%=	mod and assign	`a%=2;`

The following is legal, but not encouraged: `i=j=k=0` and is the same as `i = (j = (k = 0))`.

The operator ++ can be used in both ***prefix*** and post-fix form: in prefix form, the increment takes place before the value is used.

03Operators.c

```
int main(void)
{
  int i=1;
  printf("i++ = %d; ", i++);
  printf("++i = %d\n", ++i);
  i=1;
  printf("++i = %d; ", ++i);
  printf("i++ = %d\n", i++);
  return(0);
}
```

A **Relational Operator** tests if some relation holds between two quantities or variables, and evaluates as **true** or **false**.

Symbol	Definition
$<$	
$<=$	
$>$	
$>=$	
$==$	
$!=$	

These all evaluate as `0` for ***false*** or `1` for true.

04Logic.c

```
1  // 04Logic.c; For CS211, Jan 2019. NM
   #include <stdio.h>

   int main(void)
5  {
     int i=1, j=2;
7    printf("i=%d and j=%d\n", i, j);
     printf("i>j \t\t evaluates as %d\n", i>j);
9    printf("++i >= j \t evaluates as %d\n", ++i>=j);

11   return(0);
   }
```

Relational operators can be combined into more complex operators, as follows.

Symbol	Definition
!	
&&	
||	

See also Exercise on Slide 39

Selection statements and loops

To control the **flow** of a program, one uses

- **Selection Statements:** the main ones are `if` and `switch` – select a particular execution path. Also `?:`
- **Iteration statements:** `for`, `while` and `do`
- **jump statements:** `break`, `continue` and `goto`

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

Structure:

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

Also, `if` blocks can take the form:

Structure:

```
if( A )
  {
    perform statements if expression A evaluates
                  non-zero
  }
  else if( B )
  {
    statements if A is false, but B evaluates as true
  }
  else
  {
    statements if both A and B evaluate as false
  }
```

A trivial example

```
#include <stdio.h>
int main(void )
{
  if (10)
  {
    printf("Non-zero is always true\n");
  }
  if (0)
    {       /* dummy line */    }
  else
      printf("But 0 is never true\n");
  return(0);
}
```

Typically, however, the expressions that `if()` depends on are ***logical expressions***, based on **relational operators**, that must be evaluated.

- `a == 10`
- `c == 'n'`
- `x != 10`
- `z < y`
- `y >= z`

Logical operators, `AND`, and `OR`, allow more complex `if`-statements:

```
if( ( (i%3) == 0) && ( (i%5)==0) )
  printf("%d divisible by 15\n", i);

if( ( (i%3) == 0) || ( (i%5)==0) )
   printf("%d divisible by 3 or by 5\n", i);
```

05EvenOdd.c ⟵ link!

```
   // Check Even or Odd
18 int a=rand()%10; // a is a random number between 0 and 9.
   printf("a=%d\n", a);
20 if ( (a % 2) == 0)
     printf("a is even\n");
22 else
     printf("a is odd\n");

   // Check positive, negative or zero
26 a=rand()%7-3; // a is a random number between -3 and 3.
   printf("a=%d\n", a);
28 if ( a>0 )
     printf("a is (strictly) positive\n");
30 else if ( a<0)
     printf("a is (strictly) negative\n");
32 else
     printf("a is zero\n");
```

Exercises

Exercise (2.1)

*Suppose $x = 2$, $y = 3$ and $z = -5$. Write a C programme that check if the following statements are **true** or **false**.*

1. $(x > y) \vee (x < y)$.
2. $\big(x = (y - 1)\big) \wedge \big((y \leqslant x) \vee (y \leqslant z)\big)$.
3. $\neg(y \geqslant x - z) \vee (y \geqslant x + 1)$.