Programming in C (++) and R, MATH10017

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When and Where

Type	Time	Location
Lectures	10-11AM, Mondays	FRY BLDG LG.20
Labs*	9-11AM, Wednesdays	FRY BLDG LG.21 PC
Tutorials	5-6PM, Fridays	FRY BLDG LG.21 PC

https://www.bristol.ac.uk/timetables/html.html?unit=MATH10017

*Labs are two hours!

Key Objectives

Upon completion of this unit you should:

1. *Understand* the workflow of computer programming and appreciate computer as a data processing tool.
2. *Program*, *debug*, *document* and *test* basic algorithms in C(++) and R, with appropriate coding paradigms.
3. *Decide* which programming language to use when faced with a computing task.

How This Unit is Structured?

- TB1: C Programming Language
    - Some aspects of C++ Programming Language*.
- TB2: R Programming Language

*Some of C++'s features are designed for software engineering, not programming.

What are the Assessments?

- Written Exam (50%) at the end of TB2.
- Two Programming Coursework (25% + 25%).
    - One per TB.
    - Submit by the end of each TB.
- Non-assessed homework each week after lecture.
    - **Do not skip homework**.
    - These homework are designed to build up skills required for the final project.
    - Reuse some of the code you've written for these homework, to make your project work easier.

Your Week

- **Monday**: Attend lecture.
  - Pay attention to the homework released after lecture.
  - Write *pseudo code* of your homework.
- **Wednesday**: Go to lab.
  - Convert your *pseudo code* into actual C/R code.
  - Get help from TA/me on your homework if necessary.
  - Help each other*.
- **Thursday**: Submit your homework by 5pm.
  - Read pre-tutorial materials.
- **Friday**: Attend tutorial and engage in discussions.
  - Get feedback of your homework, ask questions.

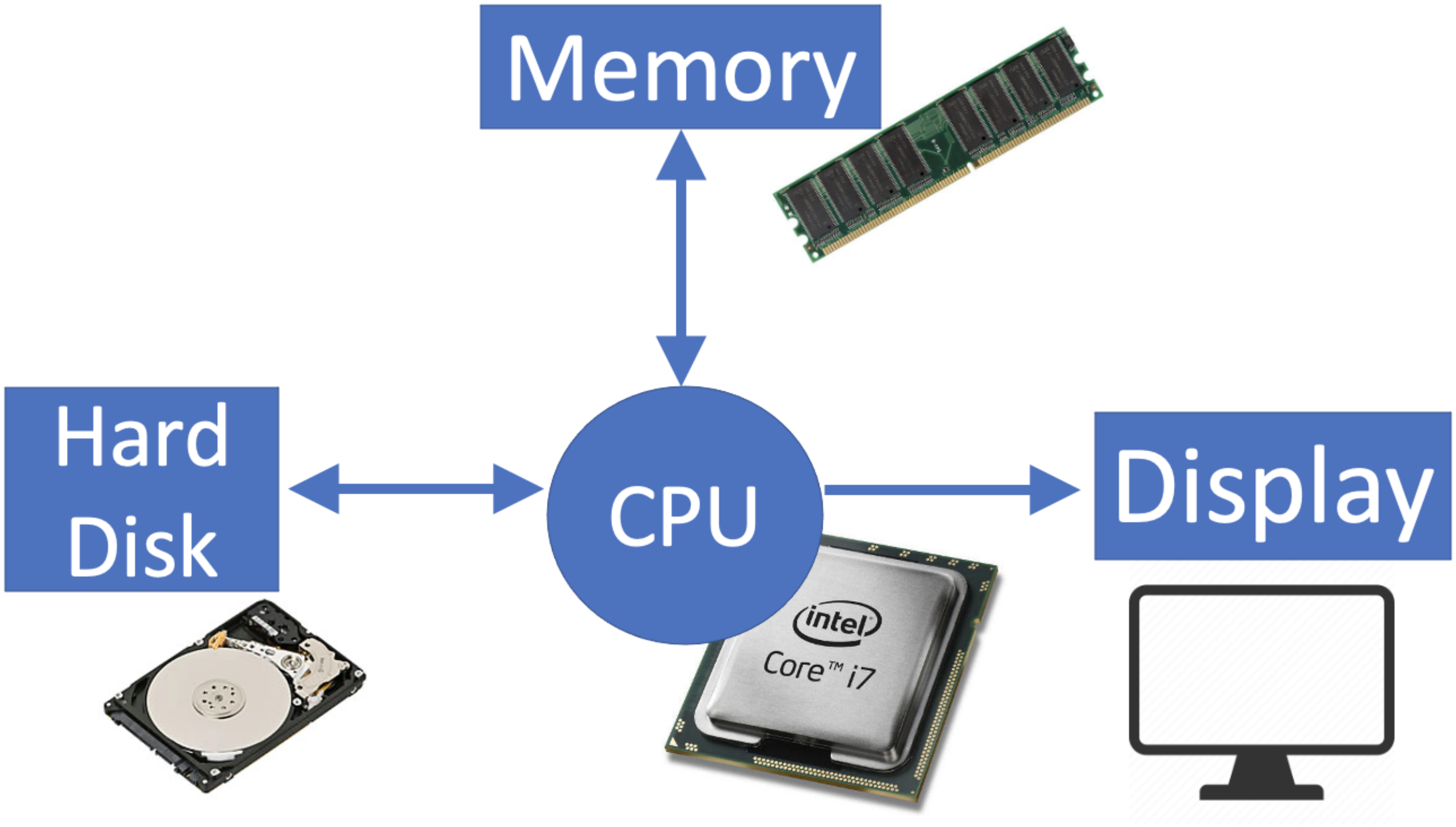
Mental Health

1. Get help early!
2. Live a structured live.

Plagiarism

- Read this guideline on Plagiarism very carefully.
- Plagiarism is a serious academic offence.
- Tips:
    - Never copy and paste from the internet.
    - Learn from other people's idea, rather than copy it.
    - Do NOT ask other people to test your code. It is your own duty to make sure your code works.
- We have many ways to detect Plagiarism.

How does Computer Work?



von Neumann Architecture

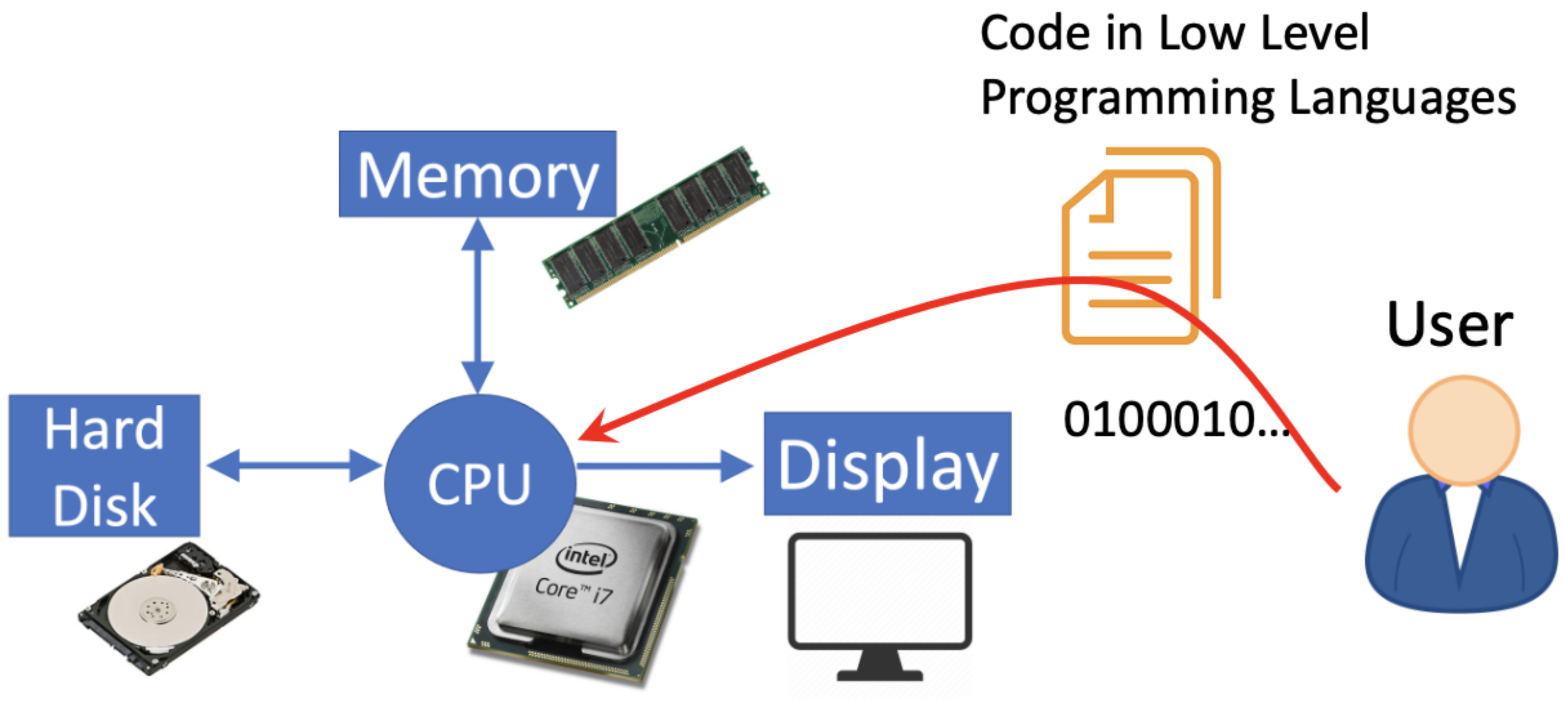
- **Central Processing Unit (CPU)**
  - Performs computational tasks.
  - Controls Input/Output (IO) devices.
  - Maintains data stored in the memory.
- **Memory**
  - Stores program/data being used by CPU temporarily.
- **IO Devices**
  - Hard disk
  - Display
  - Camera
  - Touch Screen, etc.

What is Programming?

- Programming = **writing a list of instructions to be executed on the CPU.**
- The list of instructions is called the "code".
- Programming is also called "coding".
- Programmer is also called "coder".
- The language used to write the code is called **programming language**.

Low-level Programming Language

- Coder can program in machine code.
- Then the code can be **directly executed** on the CPU requiring no (or very little) translation.
- Machine code (and its more human friendly variants) are referred to as "Low-Level Programming Languages".



Low-level Programming Language

- **Advantages** of Low-level Programming Language:
  - gives coder total control of hardware.
  - can be efficient since it needs no translation (You talk to the computer using its native language!).
- **Disadvantages** of Low-level Programming Language:
  - can damage the hardware if the coder is not careful.
  - is difficult to learn and read (machine instructions are usually very different from human languages).
  - only works on a specific computer architecture (e.g. x86 or ARM). Thus the code is not "portable".

Low-level Programming Language

Example code printing a message "Hello, World" using x86 CPUs

```
    global    start
    section   .text
start:
    mov       rax, 0x02000004
    mov       rdi, 1
    mov       rsi, message
    mov       rdx, 13
    syscall
    mov       rax, 0x02000001
    xor       rdi, rdi
    syscall
    section   .data
message:
    db        "Hello, World", 10
```

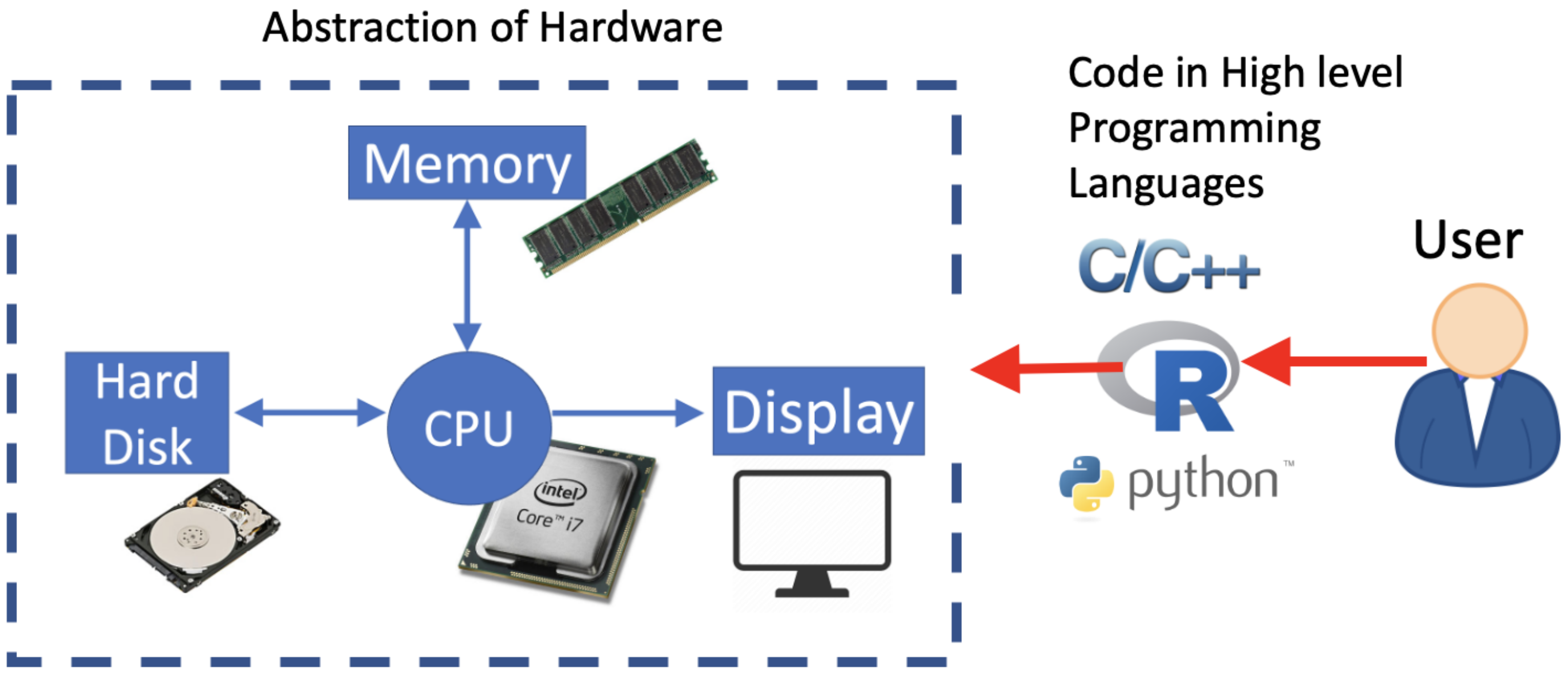
Source

High-level Programming Language

- Coder can program in a more natural language, which is then **translated** into machine code.
- This translation process is called "compilation" and the software that performs this translation is called **"complier"**.
- This kind of languages are called "High-level Programming Languages". For example,
    - C, C++
    - Python
    - Java
    - MATLAB
    - R...

Abstraction of Hardware

- Since your code is not executed on the CPU "as is", high-level language provides **an abstraction of hardware**.
- Coder interfaces with this abstraction rather than directly program for the underlying CPU and hardware.



Abstraction of Hardware

- Not allowing the user to directly program for the hardware sounds restrictive but also has many advantages:
    - The code is "portable", i.e., the coder needs not to rewrite their code for different CPU architectures, as all CPU architectures share the same abstraction.
    - The abstraction hides many cumbersome details of hardware management, so the coder can focus on their computational task.
    - Not allowing the program to have direct access to the hardware would enhance the security of the system.

Abstraction of Hardware

- However, different programming languages may provide different **levels of abstraction**.
- Some high-level programming language allows you to directly manage computational resources to some extent.
- Therefore, you can again categorize high-level programming languages into "relatively high-level" and "relatively low-level".
    - C/C++ is regarded as "relatively low-level".
    - Python/R/MATLAB are regarded as "relative high-level".

Stack Exchange: Why do some programmers categorize C, Python, C++ differently?

High-level Programming Language

- **Advantages** of High-level Programming Languages
    - Close to human language, easy to learn/read.
    - CPU architecture independent, a.k.a., "Portable".
- **Disadvantages** of High-level Programming Languages
    - Less efficient as the code requires "translation" before it can be executed on CPU.
    - Cannot directly communicate with hardware: the coder has to interface with *the abstraction*.

Example Code: C

Example C code for printing "Hello World!" on almost all CPUs.

```c
//filename: main.c
#include <stdio.h>

void main(){
  printf("Hello World!\n");
}
```

Compilation:

```
gcc main.c -o main.out
```

Execution:

```
./main.o
Hello World!
```

Dissecting C Code

```c
//filename: main.c
#include <stdio.h>

void main(){ printf("Hello World!\n"); }
```

- `//filename: main.c` : **Comments**. Readable explanations or annotations in the source code. It is ignored by complier.
- `#include <stdio.h>` : **Preprocessing command**. Instructs the compiler to perform pre-processing before the actual compilation.
- `void main(){...}` : **Function**. Contains list of statements.
- `printf("Hello World!\n");` : **Statement**. The actual command to be carried out by the computer.

The `gcc` Compiler

```
gcc main.c -o main.out
```

- `gcc`: GNU C Compiler. An open-source C programming compiler, available on Linux and MacOS.
- `main.c` C code file, as the input.
- `-o main.out` "main.out" as the output executable file (a file contains machine code, ready to be executed by CPU). On windows, use `main.exe` instead of `main.o`.

Example Code: R

Example R code for printing "Hello World!" on all platforms that run R programming language.

```
#filename: hello.R
print("Hello World!")
```

```
RScript hello.R

[1] "Hello World!"
```

There is no explicit complication. R command line (RScript) tool reads the R code line by line and automatically translates them into executable codes in real time.

More on R in the Next TB.

Development Environment

Development environment refers to the collection of software you need to write, debug (more on this later) and test your code.

To do C programming, you need two things at least:

- **Text Editor**: As C code are text files, you need a text editor to write and organize these code files.
- `gcc` : The compiler to translate your C code into machine code. It comes with most Linux installations.

This unit recommends using Visual Studio Code as your code editor. It comes with many useful features for beginners (such as syntax highlighting, code autocomplete, etc.).

Resources about C Programming

1. The C Programming Language, Brian Kernighan and Dennis Ritchie.
    i. An interview of Brian on the history of C.
2. Wikibooks: C Programming.
3. COMS10008: Imperative Programming
    i. An excellent unit use to be taught by Dr. Ian Holyer in Computer Science department.
4. CS50 is Harvard University's introductory course to computer science and the art of programming.

Conclusion

1. Programming = **writing a list of instructions to be executed on the CPU.**
2. There are two types of programming language: High level programming and low level programming.
    i. Pros and cons.
3. Two things you need to do C programming language: Text editor + Compiler!

A Pre-configured Development Environment for Fry PC Lab

- Download the Lab Pack and unzip.
- Double click "lab0.bat".
- Visual Studio Code should open. You should be presented with a "hello, world" C code example.
- Of course, you are free to configure your own development environment.

`printf` function

Builtin function `printf` displays "format string".

- printf is a shorthand for *print_formatted*.
- This function is provided by the OS and is declared in file `stdio.h`.
- To use this function, you need to add `#include <stdio.h>` at the beginning of your C code.

```
printf("FORMAT_STRING", VARIABLE1, VARIABLE2 ...);
```

- `FORMAT STRING` can contain "format specifiers".

`printf` function

- `printf` will replace all "format specifiers" in the `FORMAT_STRING` with supplied `VARIABLE` before display.
    - `printf("My name is %s %s. \n", "Song", "Liu");`
    - Prints out `My name is Song Liu.`
    - "%s": string specifier, tells computer to expect "string" type variable at this location.
    - "\n": ASCII code for "new line".
- Read this manual for a list of all possible "format specifiers" and simple examples.

Homework 1, Hello World

Setting up your Development Environment.

Test your set up with the Hello World c example above.

Homework 2, `printf`

Now, try to modify the "Hello World" example code, and accomplish the following tasks:

1. Print out your UoB ID as a string.
2. Print out your UoB ID, treating the numeral part of your UoB ID as an integer.
3. Print out the outcome of 1/3*3.
   i. Does it work?
   ii. Can you guess why it does not work?
   iii. Hint, try printing out the outcome of "1/3" and infer what went wrong.

Homework 3, `printf`

4. (submit) Print out the following table using `printf`.

```
10 Fahrenheit = -12.22 Celsius,
20 Fahrenheit = -6.66 Celsius,
...
100 Fahrenheit = 37.77 Celsius.
```

- Note: Fahrenheit temperatures are all integers, but Celsius are all decimal numbers, and only 2 characters should be displayed after the decimal point.
- You **must** make use of the conversion formula: `(F - 32) × 5/9 = C`.
- Hint: `printf("%.2f", 1.0/3.0)` prints out `0.33`.

Homework 4, `printf`

5. (submit) Print out the following triangle using `printf`.

```
|\
| \
|  \
|   \
|____\
```

- Hint: `printf("\\")` will print out `\`.

Homework 5, `printf`

4. (Challenge) `%c` specifier is for printing a single character and single character is wrapped in `''` in C Programming Language.
   i. `printf("%c\n", 'A')` prints `A`.
   ii. try `printf("%c\n", 65)` and `printf("%d\n", 'A')`, what do you see? why does it work like this?
   iii. Guess the output of `printf("%c\n", 'A'+1)`. Validate your guess.
   iv. Can you print out an emoji 😉? Hint: the "numeral code" for 😉 is four consecutive numbers, 240 159 152 137.

Feel free to look up on internet! (Do not copy and paste, of course.)