

PROGRAMMING IN PYTHON I

Basics of Programming



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Alice trying to play
croquet with a Flamingo.

The wonderland of programming

Don't get demotivated if some of your colleagues seem to play croquet while you are still struggling with your flamingo. You are not alone and it will get better. :)

[Image: Illustration (1865) by J. Tenniel, of the novel by L. Carroll, Alice's Adventures in Wonderland.
Source: https://en.wikipedia.org/wiki/Alice's_Adventures_in_Wonderland]

BEFORE WE START...
GENERAL INFORMATION ON
PROGRAMMING



Before we start...

- A computer is a machine. If you want to use it, it helps to know how it works.
- These slides shall give you a rough (unprecise) understanding about programming and computers



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 1. Structure your thoughts on how to solve a problem
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 4. Look what went wrong and go back to previous steps→ If the machine does it, you don't have to do it! :)

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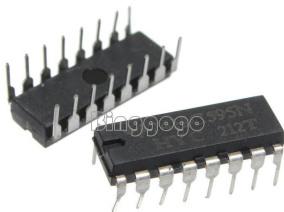
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 - The machine will do what you tell it to do
- You will be directly confronted with your own errors
- Errors in code are also referred to as **bugs**

BITS AND BYTES



Bits and Bytes (1)

- Data on computer (usually) stored in **bits**
- **Bit**: element with 2 states (True/False, 0/1, ...)
 - E.g. transistors, pneumatic elements, magnetic stripes, ...
- Registers (small storages) usually able to hold 8 bits (or multitudes of 8 bits)
 - 8 bits are referred to as **byte**
 - Often described hexadecimal numbers (i.e. 2 bytes)



Bits and Bytes (2)

- We use bits to store all kinds of data
 - Values, text, programs, images, audio, . . .
- We **encode** our data in bit patterns and later **decode** it to retrieve the meaning of the data
- Example:
 1. Right-Click on a (small) image, audio, PDF, or MS/Libre/Open Office file
 2. Open it with a text editor (notepad, texteditor, gedit)
 3. Enjoy the bit pattern of the file interpreted as pure text ;)





Note: PDF or MS/Libre/Open Office files are not only text (contain formatting information etc.)

Datatypes

- We can use a group of bits to encode a value
- There are different ways to encode values as bits
(=datatypes)
- The more bits per value we use, the more unique values we can encode (typically multitudes of bytes)
- Our main datatypes will be
 - int** Integer – Integral numbers
 - float** Float – Floating point numbers
 - string** String – (String of) characters

Datatypes: Integer

- **Integer** datatype assigns one bit-pattern to one value
 - **Precise** because no ambiguous bit-patterns
 - **Only integral numbers** in certain range

| 2 bits | decoding | value | | |
|--|----------|-------|---|---|
| <table><tr><td>0</td><td>0</td></tr></table> | 0 | 0 |  | 0 |
| 0 | 0 | | | |
| <table><tr><td>0</td><td>1</td></tr></table> | 0 | 1 |  | 1 |
| 0 | 1 | | | |
| <table><tr><td>1</td><td>0</td></tr></table> | 1 | 0 |  | 2 |
| 1 | 0 | | | |
| <table><tr><td>1</td><td>1</td></tr></table> | 1 | 1 |  | 3 |
| 1 | 1 | | | |

Datatypes: Float

- Float datatype uses the formula

$$value = significand \times base^{exponent}$$

- *significand* and *exponent* are integers and *base* is fixed

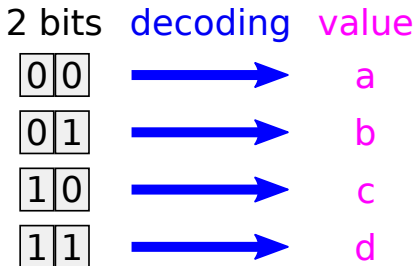
→ Not precise because values are approximated

→ Allows for floating point numbers in very large range

| 2 bits | decoding | value | | |
|--|----------|-------|---|------|
| <table><tr><td>0</td><td>0</td></tr></table> | 0 | 0 | → | 0.0 |
| 0 | 0 | | | |
| <table><tr><td>0</td><td>1</td></tr></table> | 0 | 1 | → | 0.0 |
| 0 | 1 | | | |
| <table><tr><td>1</td><td>0</td></tr></table> | 1 | 0 | → | 1.0 |
| 1 | 0 | | | |
| <table><tr><td>1</td><td>1</td></tr></table> | 1 | 1 | → | 16.0 |
| 1 | 1 | | | |

Datatypes: String

- **Character** datatype assigns one bit-pattern (typically a byte) to one **character/letter**
- Such characters are concatenated, which gives datatype **string** (we will see more about this later)
- Different encoding formats: Unicode, UTF-8, ASCII, ...



Machine Code

- Instructions to the machine (e.g. the **controller**) are also encoded in bits
 - Machine Code is often visualized as a sequence of **hexadecimal numbers**

| bit pattern | decimal | hexadecimal | command |
|-------------|---------|-------------|----------|
| 0000 | 0 | 0 | MOVE |
| 0001 | 1 | 1 | ADD |
| 0010 | 2 | 2 | MULTIPLY |
| 0011 | 3 | 3 | ... |
| 0100 | 4 | 4 | ... |
| 0101 | 5 | 5 | ... |
| 0110 | 6 | 6 | ... |
| 0111 | 7 | 7 | ... |
| 1000 | 8 | 8 | ... |
| 1001 | 9 | 9 | ... |
| 1010 | 10 | A | ... |
| 1011 | 11 | B | ... |
| 1100 | 12 | C | ... |
| 1101 | 13 | D | ... |
| 1110 | 14 | E | ... |
| 1111 | 15 | F | ... |

SIMPLIFIED EXECUTION OF A PROGRAM



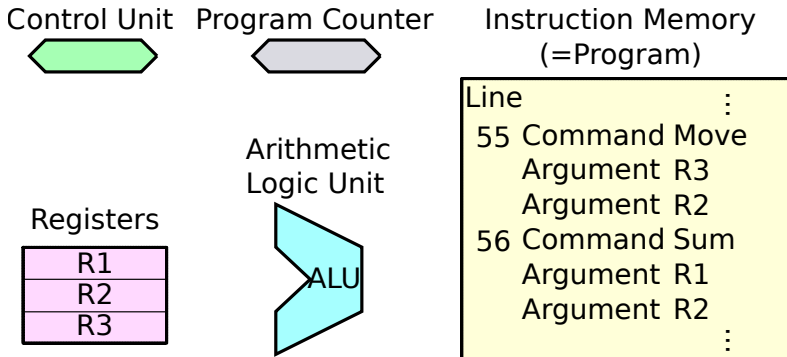
Simplified execution of a program: Setup (1)

- This section will give you a rough idea about how a program is executed
- This section ([Simplified execution of a program](#)) is not relevant for the exam but will hopefully give you some idea about the basics

Simplified execution of a program: Setup (2)

- There are several hardware parts in a controller, we will see:
 1. **Instruction Memory (IM)**: The program in machine code (e.g. stamp-card or flash-storage)
 2. **Program Counter (PC)**: Holds a value that represents the line in the code (starts at 0)
 3. **Registers (R)**: (Temporary) storage to store bit patterns
 4. **Arithmetic Logic Unit (ALU)**: Circuit that performs arithmetic operations
 - These operations often use the same specific registers as input/output (=wired to the registers)
 5. **Control Unit (CU)**: Circuit that activates registers, ALU, and Program Counter based on current bit pattern in code

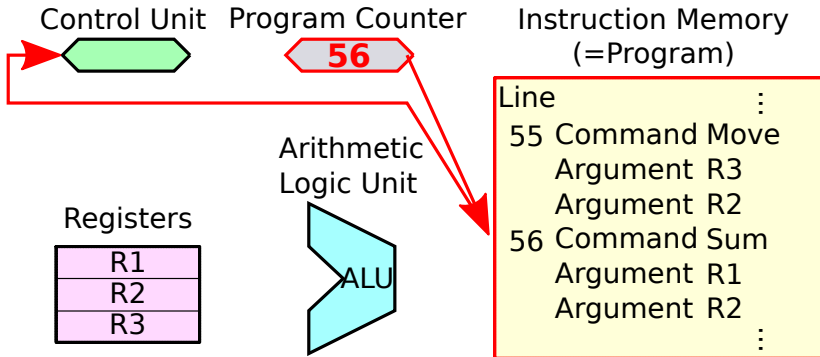
Simplified execution of a program (1)



This is our processor and on the right side we see our program (IM)

Simplified execution of a program (2)

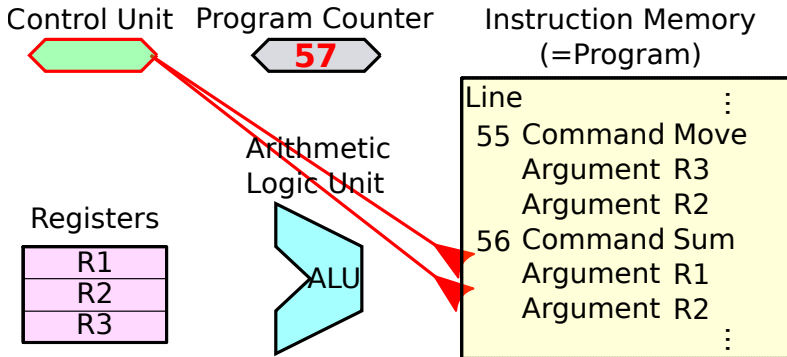
Instruction Fetch



CU fetches bit pattern from **IM** at line number stored in **PC** (e.g. 56). **CU** increases **PC** by one (e.g. to 57).

Simplified execution of a program (3)

Instruction Decode



Bit pattern Command Sum triggers **CU** to fetch next 2 bit patterns in code (adress R1 and R2) and set **ALU** to summation.

Simplified execution of a program (4)

Execution

Control Unit

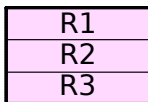


Program Counter



Instruction Memory
(=Program)

Registers



Arithmetic
Logic Unit

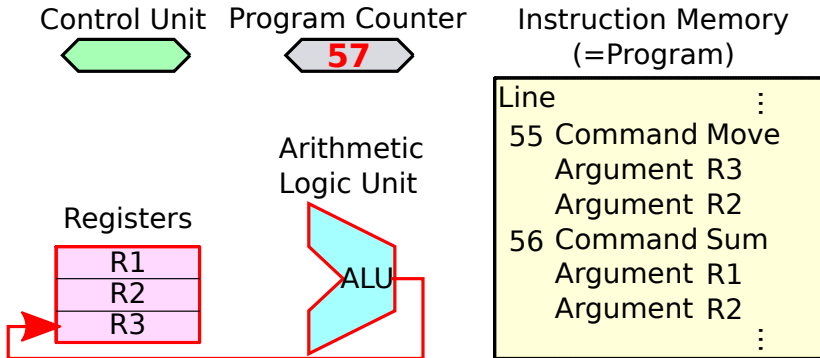


| | |
|------|--------------|
| Line | : |
| 55 | Command Move |
| | Argument R3 |
| | Argument R2 |
| 56 | Command Sum |
| | Argument R1 |
| | Argument R2 |
| | : |

ALU performs arithmetic summation with values (bit patterns) from inputs R1 and R2.

Simplified execution of a program (5)

Writeback



Result value (bit pattern) from **ALU** is stored in R3. In next step, **CU** will fetch the next bit pattern.

Simplified execution of a program (6)

- As you can see, summing up two values effectively can require more than one line of Machine Code
 1. Move values to registers
 2. Perform summation
 3. Move result from register to somewhere else
 - This can get tedious and complex/difficult to read and is highly dependent on hardware
- We would often like to get rid of (abstract from) these details/hardware

ABSTRACTION AND LANGUAGES



Abstraction and Languages (1)

Machine code Instructions as bits

Assembly Abstracts from Machine Code: More readable than bits; Still close to hardware; Very fast

C, etc. Abstracts from Assembly: Readable code; Abstracts registers and instructions; Fast because whole program is compiled and optimized at once (possibly for specific CPU architecture)

Abstraction and Languages (2)

C#, Java Abstracts even further: Readable, convenient code but often no idea about actual instructions happening; Medium/fast and still compiled at once (to architecture independent intermediary format)

Python, R Interpreted languages: Lines of code are executed one-by-one (i.e. *interpreted*) → in general no compilation of whole program but only individual lines; slow if not using specialized packages

HARDWARE



Hardware (1)

- **CPU**: Central processing unit (the actual main processor)
- **RAM**: Random-access memory (the working memory as volatile¹ storage)
- **GPU**: Graphics processing unit (computer graphics, image processing, etc.)
- **SSD**: Solid-state drive (non-volatile¹ storage via integrated circuit)
- **HDD**: Hard disk drive (non-volatile¹ storage via rotating disks)

¹ Volatile memory needs constant power in order to retain data.

Hardware (2)

- To use a computer efficiently, you have to think about which parts to use for which task
- CPU (general computations) vs. GPU (dedicated to e.g. matrix operations)
- RAM (small, fast) vs. SSD/HDD (large, slow)

Hardware – approximate operation times¹

| System Event | Actual Latency | Scaled Latency |
|-----------------|----------------|----------------|
| 1 CPU cycle | 0.4ns | 1min |
| Level 1 cache | 0.9ns | 2.25min |
| DDR RAM | 100ns | 4.17h |
| SSD I/O | 50–150μs | 86–260d |
| Rotational disk | 1–10ms | 4.76–47.56yr |

¹ Intel Xeon processor E5 v4, 2.4GHz, latency times.

Source: <https://www.prowesscorp.com/computer-latency-at-a-human-scale/>.

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Now we are through with the theory!
Let's start doing stuff! :)