

# Lesson 1

## **Computation. Algorithms. Computer Programs**

In this lesson we will talk about the following concepts: **computation**, **algorithms** and **programs**.

# ICT COMPUTER SCIENCE?



Computer Science (CS)

**But what's the difference  
between IT and CS?**

# Computer Science

Computer Science is the study of the principles of computing and how computer systems solve problems

Computer scientists design and build tools and software applications

Programming computers using mathematical algorithms, abstract concepts and models like, example the computational complexity theory

# Information Technology

IT is the study of current tools and computing techniques that can be used for technological needs of a particular organization

IT professionals apply and use these tools or software applications

IT involves more practical aspects how to use and maintain software applications, to develop, maintain and improve business processes

# Computation

# What is a Computation?

A **computation** is any type of [arithmetic](#) or non-arithmetic [calculation](#) that is well-defined.<sup>[1][2]</sup>

Common examples of computations are [mathematical equations](#) and computer [algorithms](#).

Mechanical or electronic devices (or, [historically](#), people) that perform computations are known as [computers](#). The study of computation is the field of [computability](#), itself a sub-field of [computer science](#).

A **computation** is what a **computing device** does

We sometimes call the computation, a behaviour



## Computing device

For example, a computer system, a tablet, a mobile phone or a basic calculator. But it can be as well, a non physical device, something more abstract, like an **algorithm**.

We describe a computing device by describing all its possible computations or its behaviours.

## But what is an algorithm?



Sequence of computational steps that transform the input into the output

## Example of computations

- ▶ well-defined mathematical statements
- ▶ solvable statements
- ▶ simple instructions

**Note:** There are however other problems difficult to solve or sometimes impossible to solve because there is no algorithm for them. Like the halting problem.

# The halting problem

"The halting problem is the problem of determining, from a description of an arbitrary computer program and an input, whether the program will finish running, or continue to run forever. The halting problem is undecidable, meaning that no general algorithm exists that solves the halting problem for all possible program input pairs."

# Computation as a Sequence of States

## Computation as a sequence of states

INSTRUCTION 1

INSTRUCTION 2

INSTRUCTION 3

⋮  
⋮  
⋮

INSTRUCTION N

$x = 12$       State 1  
 $y = 18$

$y = x$   
 $x = 12$       State 2  
 $y = 6$

$x = y$   
 $x = 6$       State 3  
 $y = 6$

*Initial State*

*State 1*

*State 2*

⋮  
⋮  
⋮

*State N*

## What is a computing state?

A state is an assignment of values to variables.

$$\begin{array}{l} x = 12 \\ y = 18 \end{array}$$

State 1

$$\begin{array}{l} y = x \\ x = 12 \\ y = 6 \end{array}$$

State 2

$$\begin{array}{l} x = y \\ x = 6 \\ y = 6 \end{array}$$

State 3

# Standard Computational Model

- ▶ A program execution is represented by a computation or a behaviour
- ▶ A computation is a sequence of states
- ▶ A state is an assignment of values to variables
- ▶ A program is modeled as a set of computations



# Computing devices

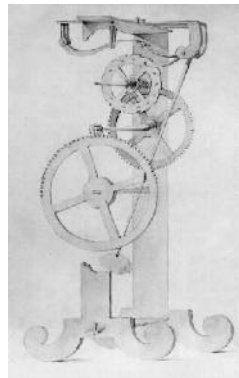
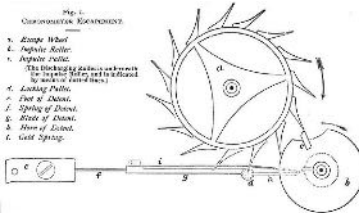
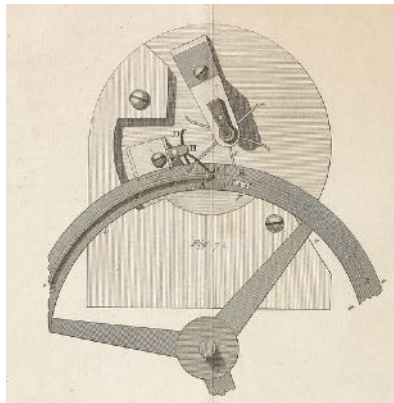
Computing devices are supposed to compute something. Like calculate and predict the weather, render to produce a movie, calculate first 1000 digits of  $\pi$

Some well-defined computations:

- ▶ calculations carried by an electronic computer or calculator
- ▶ calculations performed on a **analytical engine**, **Turing machine**
- ▶ majority of mathematical statements and calculations

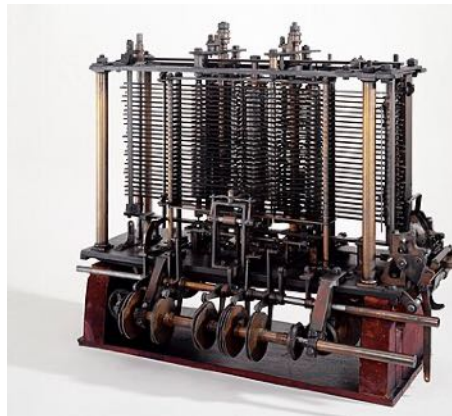
## World's first computing device?

The escapement clock, a man-made device, to keep track of time.

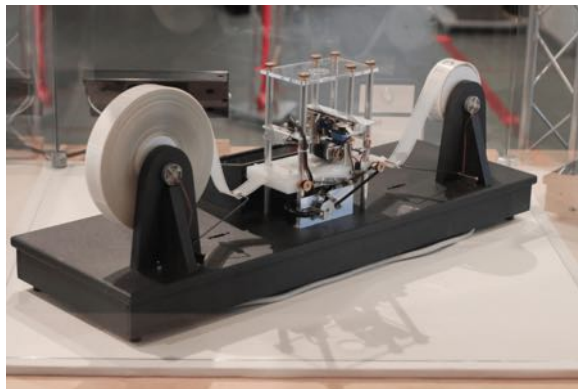


## The Analytical Engine

- ▶ The very first mechanical general purpose computer system
- ▶ Designed in 1837 by the English mathematician and computer pioneer Charles Babbage
- ▶ Built as a programmable device to solve different things



## Turing Machine



- ▶ Infinite tape, divided into cells with symbols
- ▶ A head can read/write symbols on the tape
- ▶ A register that stores the state of the machine

## Modern calculator

- ▶ Execute a number of precise operations
- ▶ Designed to contain a set of such operations and instructions
- ▶ Includes even more complex operations, graphing charting
- ▶ Example: Texas Instruments



## Single-Board Computers (SBC)

- ▶ A simple computing device
- ▶ CPU, GPU and Memory on a single chip
- ▶ Designed to run few applications
- ▶ Example: Raspberry PI



## Datacenter Servers



- ▶ Runs 24x7
- ▶ Enterprise applications
- ▶ Suitable for large number of users and applications
- ▶ Available for data-centers





Computation can be seen as a **sequence of states** a computing device does.

- ▶ Contains one or many sequence of states
- ▶ Can be an infinite number of sequence of states
- ▶ Or it can terminate with a final state

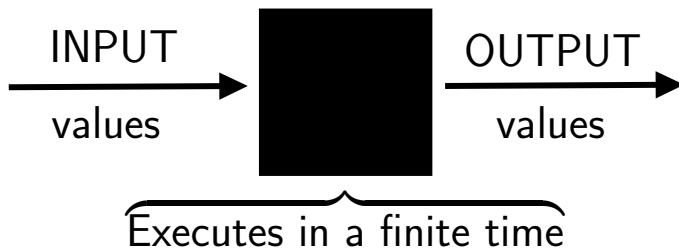
# Algorithms

# What is an algorithm?

In **mathematics** and **computer science**, an **algorithm** (**/ˈælgərɪðəm/**  ) is a **finite** sequence of **rigorous** instructions, typically used to solve a class of specific **problems** or to perform a **computation**.<sup>[1]</sup> Algorithms are used as specifications for performing **calculations** and **data processing**.

- ▶ But can we call this a **computer program**?
- ▶ Or is it just a recipe, something higher than a **sequence of code**
- ▶ A higher level of abstraction of how to implement something we plan to develop. Example: how to find a name in a phone book

# What is an algorithm?



Sequence of computational steps that transform the input into the output

### **Algorithms are everywhere**

From your kitchen, in your microwave oven, your washing machine, to your phone or computer. When you browse Internet web sites your web browser is using different algorithms to decide how to display data to you.

Our society relies on algorithms to suggest sentences for convicted criminals. You even use algorithms to keep you alive: the control systems from your car, or in different medical devices.

### But how can we describe them?

As an abstraction of something you plan to build or use, including all basic operations to achieve that. For example, think you plan to search in a phone book, a person phone number by the name:

- ▶ you can start page by page searching for that name
- ▶ or you can jump directly to certain letters and start following from there
- ▶ or you can apply a different strategy, by 'cutting' the book into half, checking the letter in which half belongs, and applying all over again the same principle until the name is found

### How can we write one algorithm?

You can write it in plain English or in a more precise way using mathematics. Some others are using a form of **pseudocode**.

In **computer science**, **pseudocode** is a description of the steps in an **algorithm** using a mix of conventions of **programming languages** (like **assignment operator**, **conditional operator**, **loop**) with informal, usually self-explanatory, notation of actions and conditions.<sup>[1][2]</sup> Although pseudocode shares features with regular **programming languages**, it is intended for **human** reading rather than machine control. Pseudocode typically omits details that are essential for machine understanding of the algorithm. The programming language is **augmented** with **natural language** description details, where convenient, or with compact **mathematical notation**.

### Example phonebook

```
1: procedure PHONEBOOK( $N$ )           ▷ Returns person name:  $N$ 
2:    $N \leftarrow 1$ 
3:   Open page number  $N$ 
4:   Look at the page  $N$ 
5:   if Person is on page  $N$  then
6:     Call person  $N$                  ▷ The person name is  $N$ 
7:   else
8:     Find next page.  $N \leftarrow N + 1$  Go back to 3
9:   end if
10: end procedure
```



### **But why not using a programming language?**

We must think what we are planning to do, and how we plan to do it. And for that, we must not rely on a programming language: we will be restricted by the limits of the specific programming language not being able to design and think freely about it.

A better approach is to think to write it as pseudocode or simple mathematics. This way we can have all flexibility and the power of precise mathematics.

### Euclid's Algorithm or GCD

In [mathematics](#), the **Euclidean algorithm**,<sup>[note 1]</sup> or **Euclid's algorithm**, is an efficient method for computing the [greatest common divisor](#) (GCD) of two integers (numbers), the largest number that divides them both without a [remainder](#). It is named after the ancient Greek [mathematician Euclid](#), who first described it in [his \*Elements\*](#) (c.300 BC). It is an example of an [algorithm](#), a step-by-step procedure for performing a calculation according to well-defined rules, and is one of the oldest algorithms in common use. It can be used to reduce [fractions](#) to their [simplest form](#), and is a part of many other number-theoretic and cryptographic calculations.

### Euclid's Algorithm

Greatest Common Divisor (GCD) of two numbers A and B is the largest number that divides both A and B. (Number here defined as an **integer**)

An integer is the number zero (0), a positive natural number (1, 2, 3, etc) or a negative integer with a minus sign (-1, -2, -3, etc) In mathematics we call this  $\mathbb{Z}$  set of numbers.

### Euclid's Algorithm

The very first version:

If  $A = 0$  then  $\text{GCD}(A,B)=B$ , since the  $\text{GCD}(0,B)=B$ , and STOP

If  $B = 0$  then  $\text{GCD}(A,B)=A$ , since the  $\text{GCD}(A,0)=A$ , and STOP

Write  $A$  in quotient remainder form ( $A = B * Q + R$ )

Compute then  $\text{GCD}(B,R)$  since  $\text{GCD}(A,B) = \text{GCD}(B,R)$

### Euclid's Algorithm, pseudocode

```
1: procedure GCD( $A, B$ )  
2:    $R \leftarrow A \bmod B$   
3:   while  $R \neq 0$  do  
4:      $A \leftarrow B$   
5:      $B \leftarrow r$   
6:      $R \leftarrow A \bmod B$   
7:   end while  
8:   return  $B$   
9: end procedure
```

▷ The g.c.d. of  $A$  and  $B$

▷ We have the answer if  $R$  is 0

▷ The gcd is  $B$

### Euclid's Algorithm, improved

```
1: procedure EUCLID( $A, B$ )  
2:   if  $B == 0$  then  
3:     return  $A$   
4:   else  
5:     return EUCLID( $B, A \bmod B$ )  
6:   end if  
7: end procedure
```

▷ The g.c.d. of  $A$  and  $B$

▷ The gcd is  $A$

### Euclid's Algorithm, using mathematics

MODULE *Euclid*

EXTENDS Integers

VARIABLES  $x, y$

CONSTANTS  $a, b$

$Init \triangleq (x = a) \wedge (y = b)$

$Next \triangleq (x > y$   
     $\wedge x' = x - y$   
     $\wedge y' = y)$

$\vee (y > x$   
     $\wedge y' = y - x$   
     $\wedge x' = x)$

**But how do we know our  
algorithm does the right thing?**



**”An algorithm for a computational problem is **CORRECT** if, for every problem instance provided as input it **HALTS**, finishes its computing in finite time and outputs the correct solution to the problem instance”**

A correct algorithm **SOLVES** the given computational problem

**An incorrect algorithm might not HALT at all on some input instances, or it might halt with an incorrect answer**

### Classes of algorithms

- ▶ Divide and Conquer
- ▶ Sorting
- ▶ Searching
- ▶ Dynamic programming
- ▶ Greedy algorithms
- ▶ Graph algorithms
- ▶ Shortest path
- ▶ Maximum flow
- ▶ Parallel algorithms
- ▶ Matrix operations
- ▶ Online algorithms
- ▶ Machine learning
- ▶ Linear programming
- ▶ String matching

# How about AI?

## Still an algorithm

- ▶ Or more precisely many algorithms
- ▶ Complex algorithms
- ▶ But still algorithms nevertheless

# Should humans be kind to AI machines? | BBC News



**Algorithms  
don't feel  
Data does  
not suffer**

Algorithms **dont feel** are not **conscious,**  
**sentient beings!**

# We need safe and secure software

- ▶ predictable - which we can CONTROL
- ▶ not harmful - USEFUL to us
- ▶ being able to STOP it if we want



**This is not about being nice, but rather being able to describe and proof that our algorithms do the right thing and do it efficiently based on mathematical tools**

This is what we need.

# Computer Programs

# What is a computer program?

A **computer program** is a **sequence** or set of instructions in a **programming language** for a **computer** to **execute**. It is one component of **software**, which also includes **documentation** and other intangible components.<sup>[1]</sup>

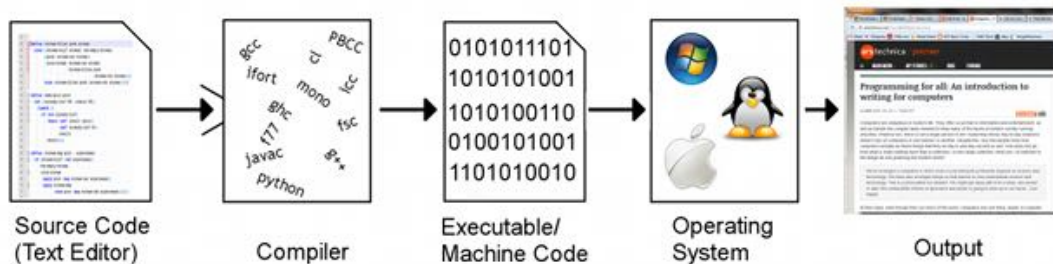
## Program. Computation. States

- ▶ A program execution is a computation (behaviour)
- ▶ A computation is a sequence of states
- ▶ A state is an assignment of values to variables

A program is modeled as a set of computations, representing all possible program executions

Computers, digital systems are executing programs

## From source code to executable



# Program structure

A **computer program** is a **sequence** or set of instructions in a **programming language** for a **computer** to **execute**. It is one component of **software**, which also includes **documentation** and other intangible components.<sup>[1]</sup>

- ▶ Some programs run forever, some dont
- ▶ A program execution is defined by at least one computation
- ▶ A computation is a sequence of states
- ▶ And a state is an assignment of values to variables

# Program types

- ▶ A program is modelled by a set of computations, representing all possible executions
- ▶ Remember an algorithm is just an abstract program
- ▶ Different programs: software applications and system software
- ▶ System software: operating systems



## Application and System Programs

- ▶ **Software applications:** enterprise resource planning, customer relationship management, supply chain management software, web, middleware, databases
- ▶ **Operating systems:** macOS, RedHat, FreeBSD, Windows



# Lesson 1

## Programs

