Programming Languages

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Outline

- What is programming
- What are programming languages
- Understanding compilation and execution
- Comparison between C, C++, Java, Python, Bash
- Additional material

General concepts in programming

- **Programming** is the process of writing a **computer program,** that is, *translating an idea* into something that can be **executed** by a computer.
- This *translation* happens in several steps and, like a recipe for cooking a meal, one needs to understand the *ingredients* and how to *mix/cook* them.
- The *idea* usually takes the form on an **algorithm**.

Ingredients of programming: What is an **algorithm**?

- A **finite sequence of instructions** to carry out a task or solve a problem.
- An algorithm can be written in natural language or in mathematical terms.
- The term is derived from the name of the Islamic scholar Al-Khwarizmi.

Ingredients of programming: Code

- Code or *source code*
  - Is a **structured description** of an algorithm, it determines what a program will do
  - It is usually stored in digital format on one or more **files**
  - The description is usually done via a **programming language**
    - It is called **language** because one must respect several *grammar rules*, like in spoken or written natural human languages.

From algorithm to code

- The **translation of an algorithm into code**, using a programming language, is called **implementation**
- The transition between an algorithm and and its implementation can have an intermediate representation that is still human readable, which mixes natural language and programming language. This is often called **pseudo-code**.
    - Writing pseudo-code is one of the best techniques to implement an algorithm, although can be time consuming.

What is source code like?

- It is a list, a **sequence of statements**, also called **lines of code**.
- These statements usually come in a defined **structure**, that is, **an order** in which one should write them
- It can be stored digitally in one or more text **files**
- It can refer to other programs or program components, often called **libraries**

Ingredients of programming: Code example

Code might look weird at first. But there is a strive to make it human-readable. Consider the following example of **C** code, what do you think it does?

```
printf ("%s \n", "Hello World!");
```

Ingredients of programming: Code example

Yes, it `prints` on screen the text *string*

```
Hello World!
```

Let's analyze the componets of the language **statement**:

```
printf ( "%s \n", "Hello World!" );
```

Issue a command:
function or procedure `printf();`

Command argument:
two function arguments

1. Formatting information:
   - “`%s \n`” means “I want you to print a string (`%s`) and then go to next line (`\n`)
2. Content information:
   “`Hello World!`” is the actual thing to print.

Grammar syntax:
<function name>**(**<argument or parameter>**);**

WARNING:
NOT A MATHEMATICAL FUNCTION!!!!

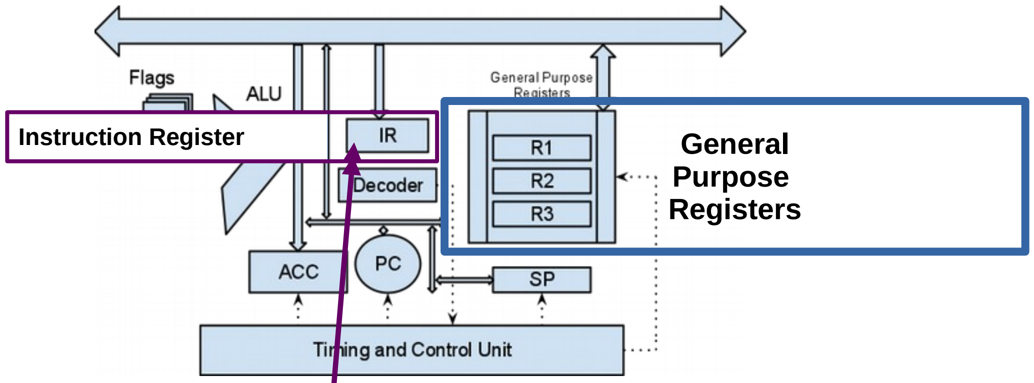
Machine Language: Binary Code

- A computer instruction is a **sequence of bits**, that is, zeroes and ones.
- A binary instruction is also called **opcode**, Operation Code
- For simplicity, each instruction corresponds to a human-readable string, called **Assembly Instruction**
- The following table shows shows examples of instructions, where the letters identified by dollars denote an operand.
- Operands **are not values**, but identify **one Processor Register**.
  Processor registers are small memory inside the CPU itself that the CPU uses to work; each has a number that identifies it.
  A register contains the actual values that the operation will use.

Instruction	Opcode/Function	Syntax	Operation
add	100000	ArithLog	$d = $s + $t
addu	100001	ArithLog	$d = $s + $t
and	100100	ArithLog	$d = $s & $t

$d	ID of destination register
$s	ID of source register
$t	ID of second source register

Machine Language: Binary Code



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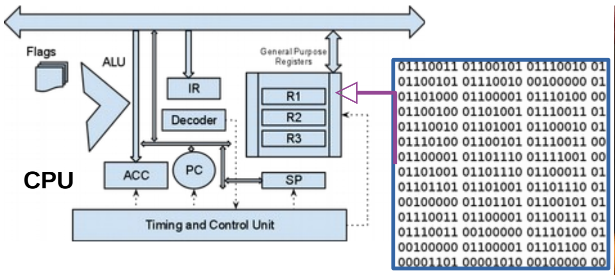
Programming languages: A brief history

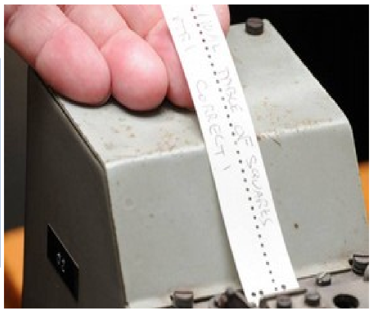
Modern classification of programming languages is based on generations. As generation increases, the languages are closer to the human way of expressing concepts.

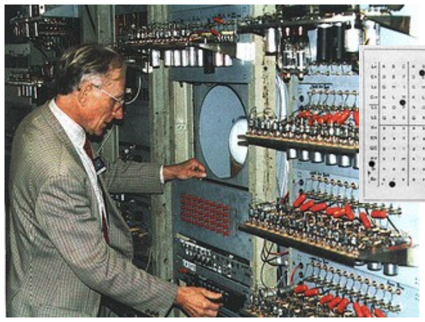
- 1st generation. **Machine code** language. This includes carboard and **binary code**. Machine dependent.
- 2nd generation. **Assembly** or instruction-based languages. Still used in embedded programming, but through 3rd generation ones. Machine dependent.
- 3rd generation. Also called **High-Level** programming languages. Mostly use **English** to describe commands. **Machine independent.**
  These include: C, C++, C#, Java, Javascript, Python, Bash, PHP, Pascal, Fortran...
- 4th generation. Domain specific languages. Report or Form generatorn, or Data manipulation. Examples: Mathematica, Matlab, SPSS, R (statistics)
- 5th generation. Mathematical or logical languages. Solving problem by specifying constraints, without focusing on the algorithm. Mainly used in artificial intelligence research. Examples: Prolog, NetLogo.

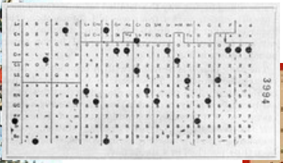
1st generation: Machine Language

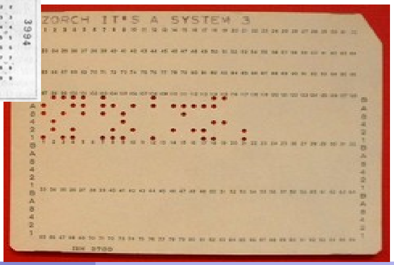


```
01110011 01100101 01110010 01
01100101 01110010 00100000 01
01101000 01100001 01110100 00
01100100 01101001 01110011 01
01110010 01101001 01100010 01
01110100 01100101 01110011 00
01100001 01101110 01111001 00
01101001 01101110 01100011 01
01101101 01101001 01101110 01
00100000 01101101 01100101 01
01110011 01100001 01100111 01
01110011 00100000 01110100 01
00100000 01100001 01101100 01
00001101 00001010 00100000 00
```



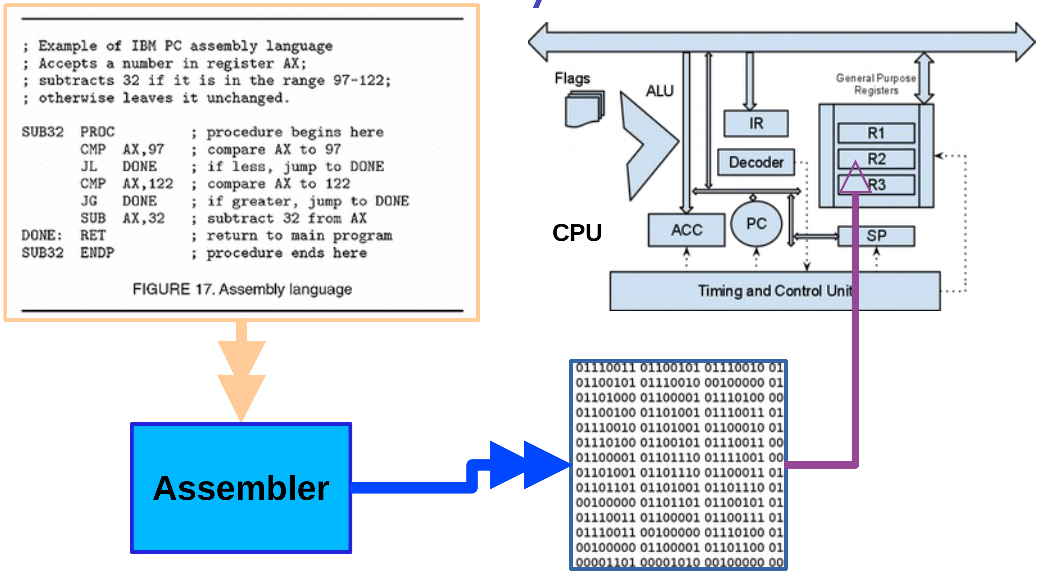






- Minimal instructions set in binary code: binary sequences corresponding to operations like move, read, sum, multiply...
- Direct edit of CPU Registries, Memory Pointers, Start of Program Counter
- Direct programming, not portable, specific for a determined machine.

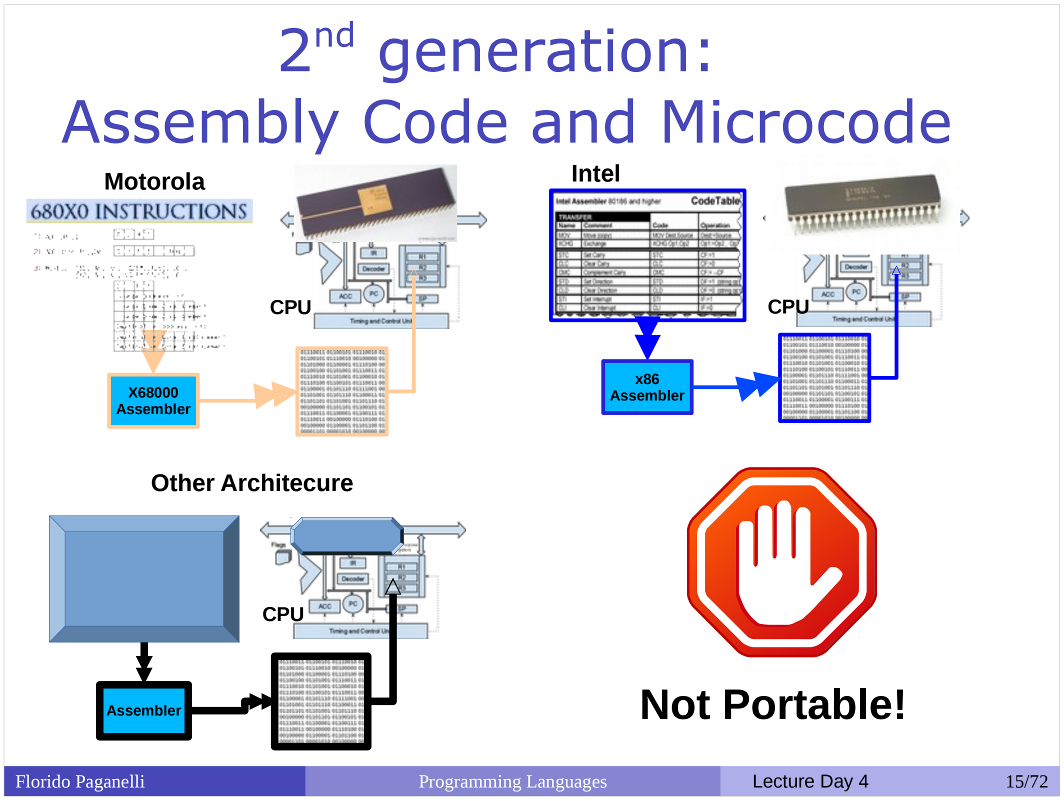
2nd generation: Assembly Code


```
; Example of IBM PC assembly language
; Accepts a number in register AX;
; subtracts 32 if it is in the range 97-122;
; otherwise leaves it unchanged.

SUB32  PROC          ; procedure begins here
       CMP  AX,97    ; compare AX to 97
       JL   DONE     ; if less, jump to DONE
       CMP  AX,122   ; compare AX to 122
       JG   DONE     ; if greater, jump to DONE
       SUB  AX,32    ; subtract 32 from AX
DONE:  RET           ; return to main program
SUB32  ENDP          ; procedure ends here
```

FIGURE 17. Assembly language

```
01110011 01100101 01110010 01
01100101 01110010 00100000 01
01101000 01100001 01110100 00
01100100 01101001 01110011 01
01110010 01101001 01100010 01
01110100 01100101 01110011 00
01100001 01101110 01111001 00
01101001 01101110 01100011 01
01101101 01101001 01101110 01
00100000 01101101 01100101 01
01110011 01100001 01100111 01
01110011 00100000 01110100 01
00100000 01100001 01101100 01
00001101 00001010 00100000 00
```



2nd generation: Assembly Code and Microcode

- Each instruction is represented by an **opcode** and its **arguments**.
- A more human readable language is introduced, **assembly**, that maps each opcode and arguments to a human readable syntax.
  - The program used to code is called **assembler**, takes in input a sequence of assembly statements and translates them into binary code
- New CPUs emerge that contain a more complex instruction set called **microcode**, stored physically in a ROM inside the CPU: a single instruction can do more than a single operation. Different assembly for different architectures.
  - **Not portable**: code can only be used for a specific machine.
- Used for home computers, nowadays for small devices.

3rd generation: Human-oriented

- **Algorithm oriented**: the user translates an algorithm into language commands
- Introduces programming *paradigms*:
  - **Imperative**
  - **Object Oriented**
  - Functional
  - … more!
- Introduces various translation to machine language methods:
  - Compiled
  - Interpreted
  - Bytecode interpreted

Imperative languages

- Programming style that describes computation in terms of a **program state** and **statements** that **change** the program state.
- Adheres to the *separation of code and data* principle.
- Examples: C, FORTRAN, Python, Bash
- Remember `printf ("%s \n", "Hello World!");` ?

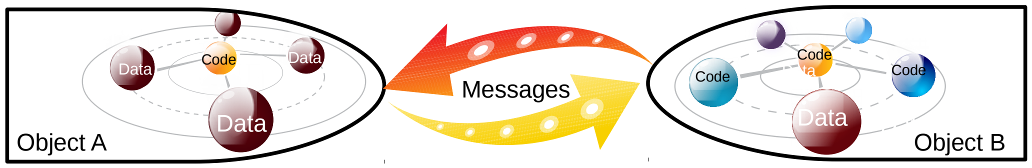
Code

Data

Object-oriented languages

- A computer program is a **collection of objects** that act on each other.
- Each object is capable of **sending and receiving messages** and **processing data**. Each object is independent.
- An object is a ‘black box’ which sends and receives messages, and consists of **code** (computer instructions) and **data** (information which these instructions operate on).
- Breaks the *separation of code and data* principle.

⚠ Examples: Java, C++, Python



Ingredients of programming: Data

- Often provided by the user
- NOT code, but *used* by code to do things
- Carries **information**, most likely understandable by a scientist.
- **Input data**: provided in input **to** the code to process information.
  - Example: the formatting information `"%s \n"`, and the text string `"Hello World!"`
- **Output data**: the result of the code execution, that will be generated as output **from** the code execution.
  - Example: the output string `Hello World!`

Separation of Code and Data principle

- Code is information about **logic**, **arithmetics** and **algorithms**.
  - One can think of it like a matematical function, that defines a domain and codomain in generic terms.
- Data is information that is **to be read, processed, written**.
  - **Input** data **should be left untouched and not modified**. Think about is as a science fact or empirical/experimental data.
    - One does modify it in memory while running a program, but the changes should never be written back to the original data (would pollute science facts!)
  - **Output** Data is usually **the result** of something code did on it. For ease of use, it might be represented the same way as Input Data.

Separation of Code and Data Mathematical example

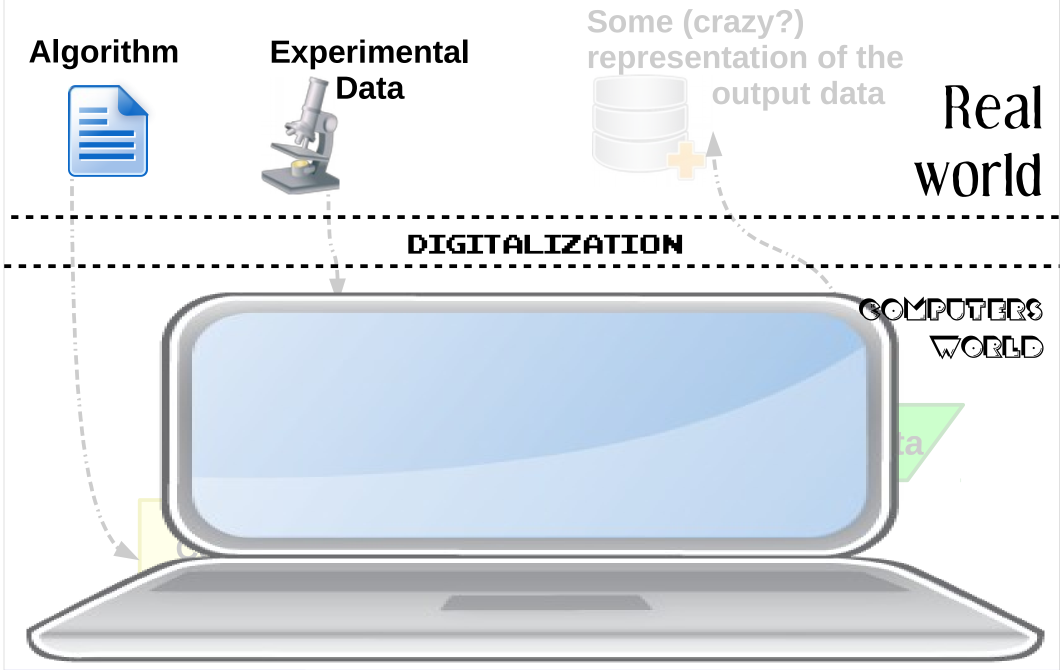
- Goal: Given a set of positive integer numbers, give all the possible sums of each couple of such numbers.
- Input data:
  - The set of numbers I={1,2,3}.
- algorithm using math syntax and natural language:

  $1.\, sums(x,y)=x+y\,;\, x,y\in\mathbb{N}$

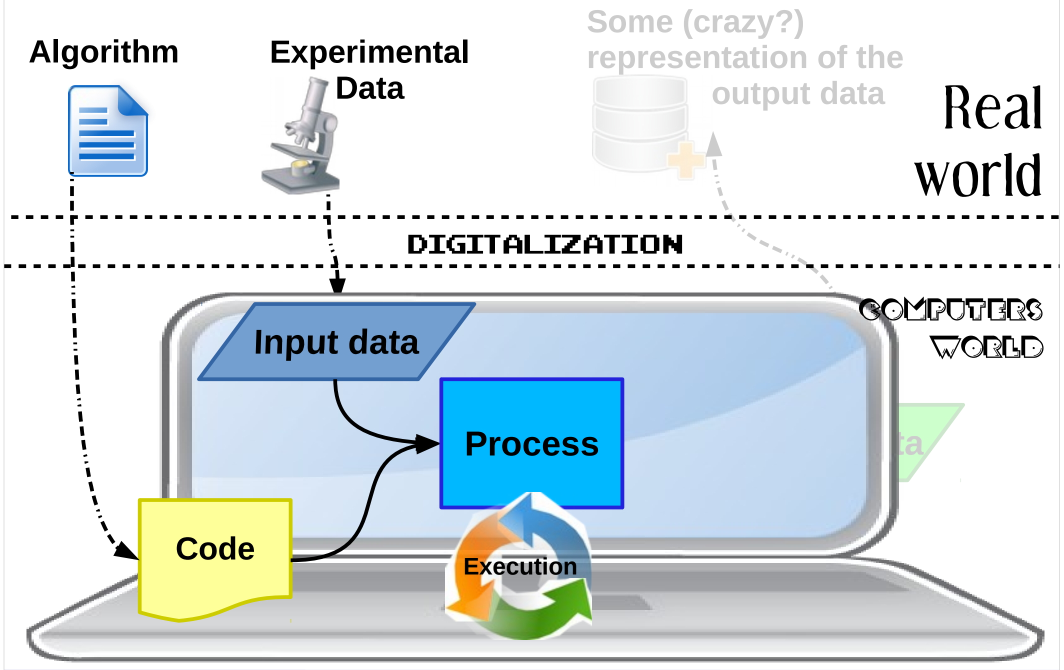
  $2.\, pairsums(I)=n\in\mathbb{N}\, such\ that\ sums(i,j)=n,\, for\ all\ i,j\in I$

  $3.\, Calculate\ pairsums(\{1,2,3\})$
- Output data:
  - O={2,3,4,5,6}

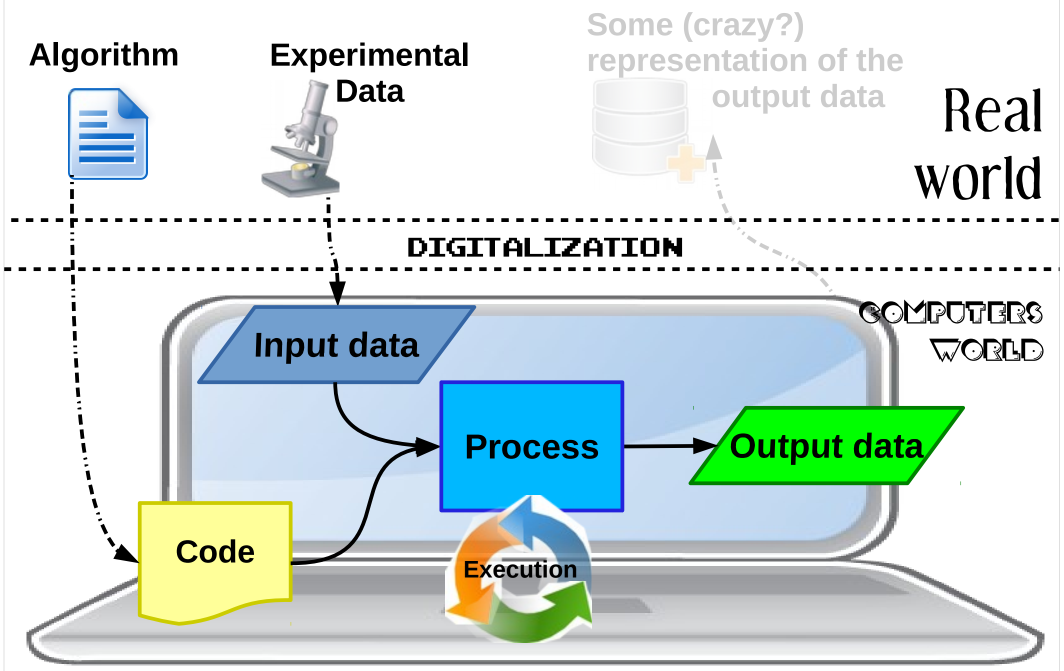
The information flow



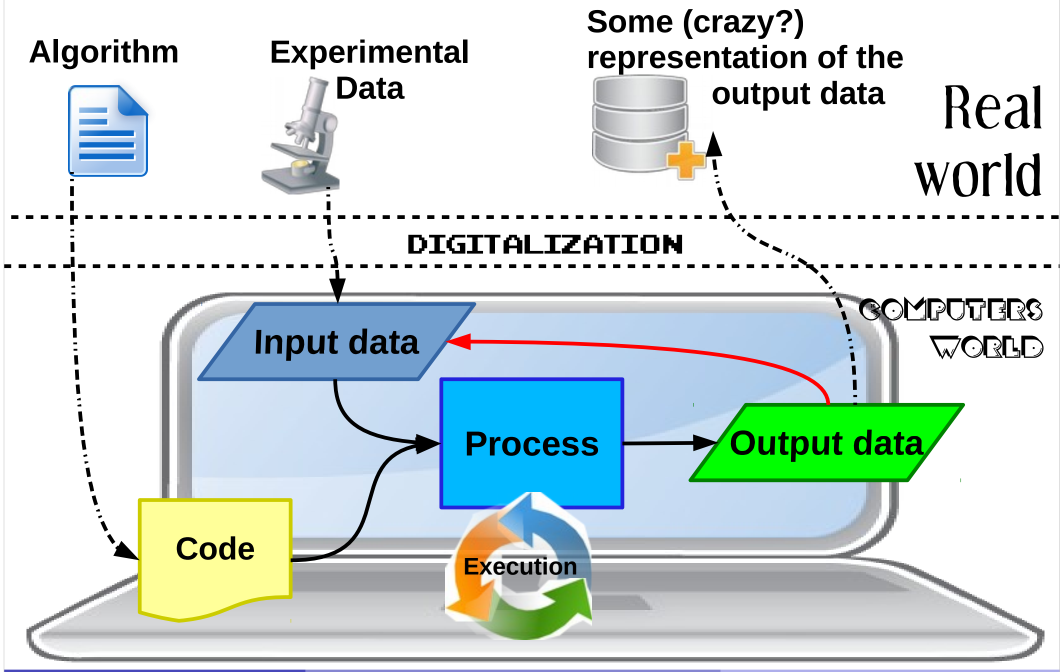
The information flow



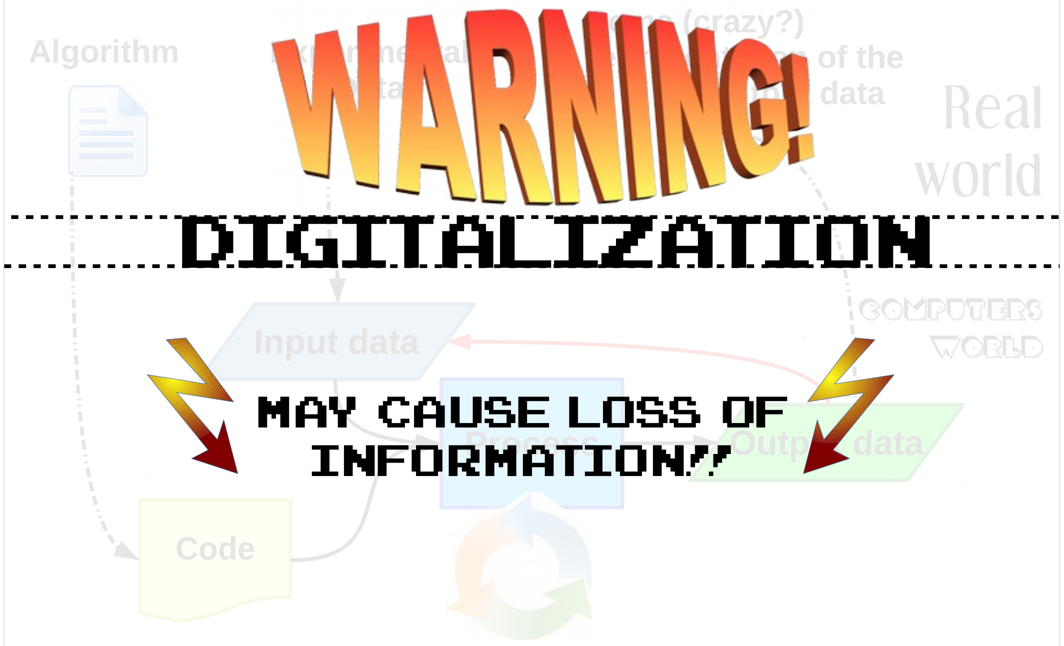
The information flow



The information flow



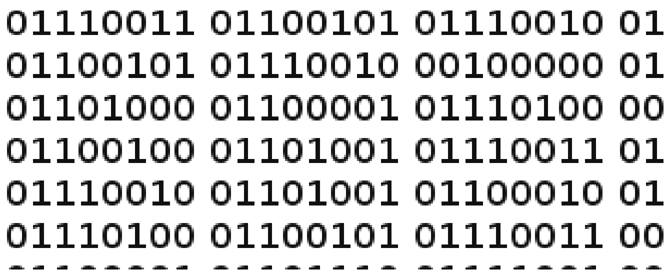
The information flow



From code to machine language

- A **process** is a program that is *executing* in a computer.

- To be executed by a computer, a program must be written in **machine language**.
- Machine language is **binary code**:

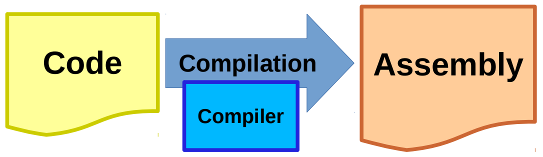


```
01110011 01100101 01110010 01
01100101 01110010 00100000 01
01101000 01100001 01110100 00
01100100 01101001 01110011 01
01110010 01101001 01100010 01
01110100 01100101 01110011 00
```

How does one go from **code** to **machine language**?

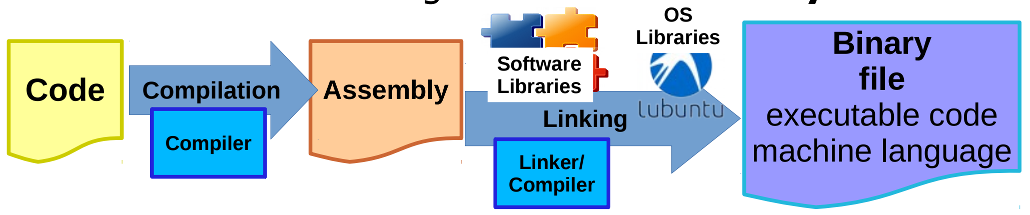
From code to machine language

- The *translation* of **code** written in a certain **programming language** is called **compilation**.
- Is performed by a special program called the **compiler.**
- The first step of compilation transforms Code into Assembly Code.



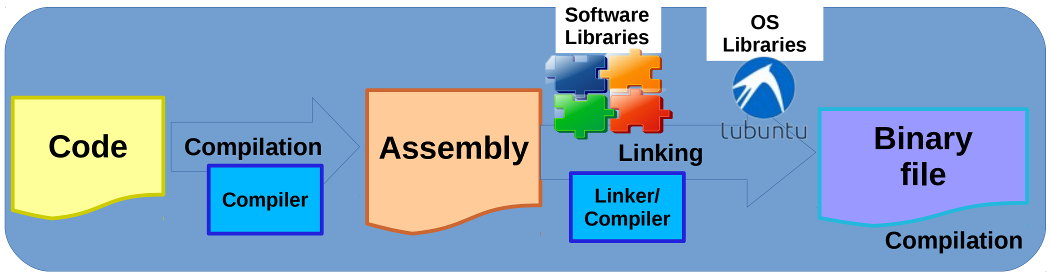
From code to machine language

- The *translation* of **assembly code** to **executable code** or **machine language** is called **linking**.
- The **Linker**:
  - Binds the software to specific Operating System functions, the **system libraries**
  - Adds **external libraries** to the written code (i.e. scientific libraries for advanced computation)
  - Translates the Assembly code into machine language.
- The result of linking is also called **binary file**



From code to machine language

- The term **compilation** is commonly used for both the process of Compiling and Linking, as it is very hard to decouple them in practice.



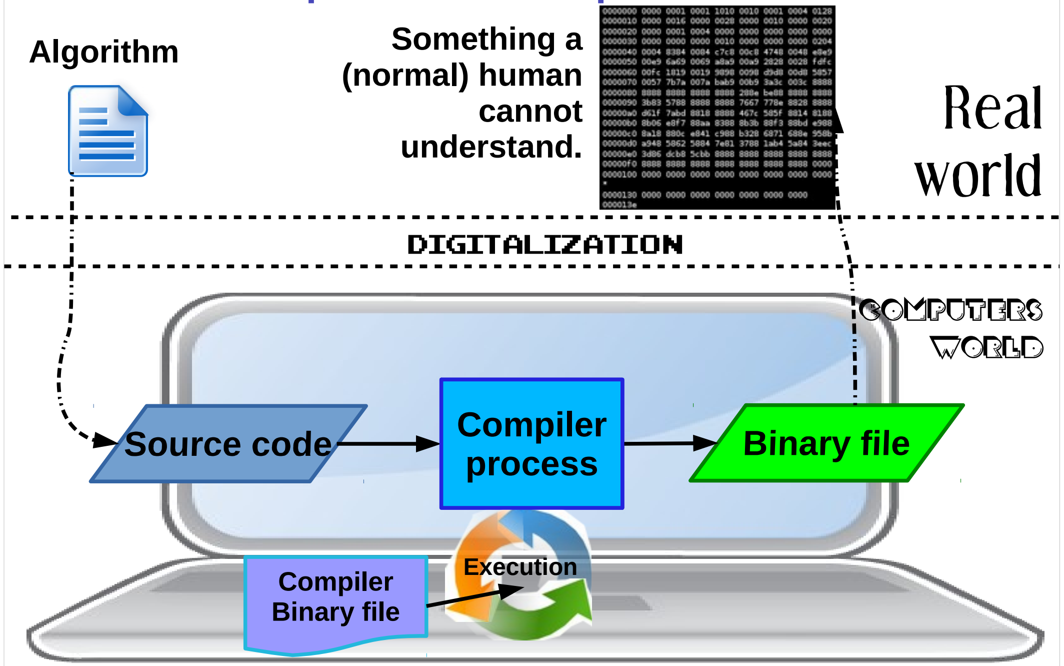
Steps to compilation

- A scientist writes his own code, also called **source code**.
- Source code is provided as Input data to the **compiler**.
- The compiler process runs, compiles and links the code and then generates **compiled and linked binary code**.
- The binary code is written to a file as Output data, the result of the compilation process is hence a **binary file**.

Execution

- **Execution** of a binary file is the task of
  1) *Loading* it into the computer memory (RAM)
  2) *Tell* the processor (CPU) to *start processing* the instructions just loaded in memory
- In modern machines this is simplified by
  - touching an app icon (phones)
  - double clicking on an icon (most of graphical interfaces)
  - explicitly writing the name of the program to run using command line interfaces (e.g. BASH).

Steps to compilation

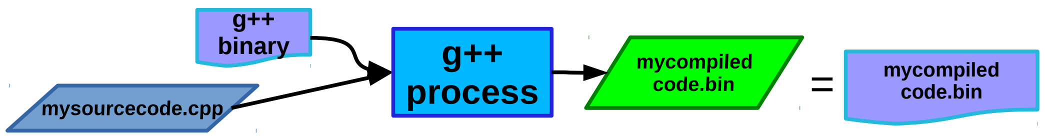


```
0000000 0000 0001 0001 1010 0010 0001 0004 0128
0000010 0000 0016 0000 0028 0000 0010 0000 0020
0000020 0000 0001 0004 0000 0000 0000 0000 0000
0000030 0000 0000 0000 0010 0000 0000 0000 0204
0000040 0004 8384 0084 c7c8 00c8 4748 0048 e8e9
0000050 00e9 6a69 0069 a8a9 00a9 2828 0028 fdfc
0000060 00fc 1819 0019 9898 0098 d9d8 00d8 5857
0000070 0057 7b7a 007a bab9 00b9 3a3c 003c 8888
0000080 8888 8888 8888 8888 288e be88 8888 8888
0000090 3b83 5788 8888 8888 7667 778e 8828 8888
00000a0 d61f 7abd 8818 8888 467c 585f 8814 8188
00000b0 8b06 e8f7 88aa 8388 8b3b 88f3 88bd e988
00000c0 8a18 880c e841 c988 b328 6871 688e 958b
00000d0 a948 5862 5884 7e81 3788 1ab4 5a84 3eec
00000e0 3d86 dcb8 5cbb 8888 8888 8888 8888 8888
00000f0 8888 8888 8888 8888 8888 8888 8888 0000
0000100 0000 0000 0000 0000 0000 0000 0000 0000
*
0000130 0000 0000 0000 0000 0000 0000 0000
000013e
```

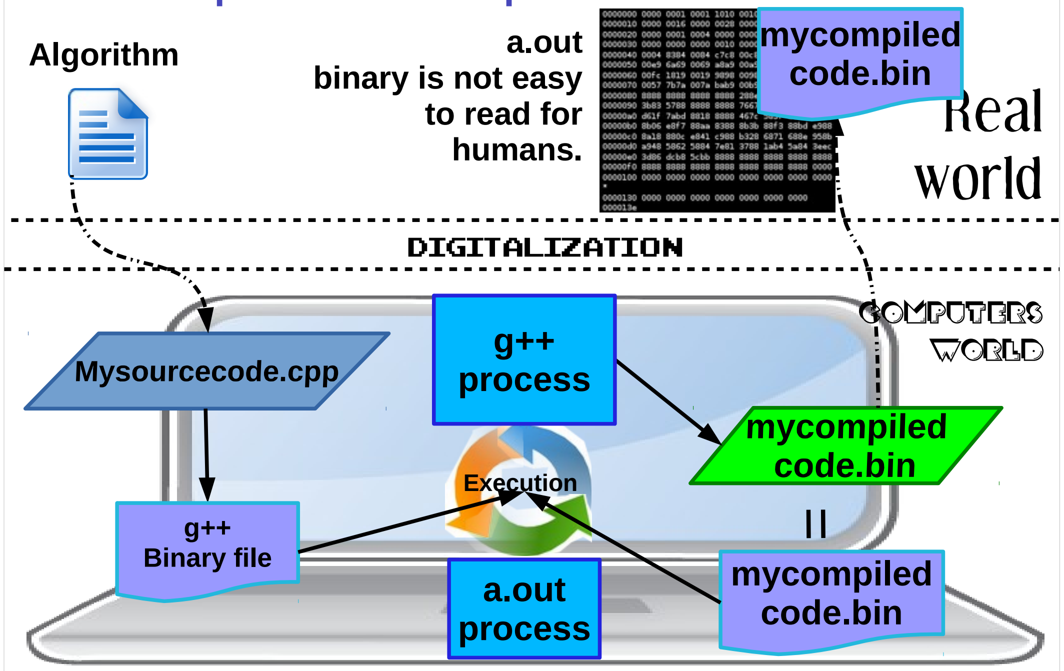
Compiled languages

- Classic programming languages like C or C++ are said to be **compiled** as the creation of an executable works as shown in the previous slides.
  - The developer will have to

  1) **Compile** her *source code*
  Example: compile a C++ source file and generate a binary file `mycompiledcode.bin`:
  `g++ -o mycompiledcode.bin mysourcecode.cpp`
  - **run** or **execute** the binary code to see his program in action.
  Example: run `mycompiledcode.bin` binary file
  `./mycompiledcode.bin`
- Note: `mycompiledcode.bin` is an output file. `g++` and `mycompiledcode.bin` are binary files. g++ is a program that generates binary files as its output.



Steps to compilation: C++



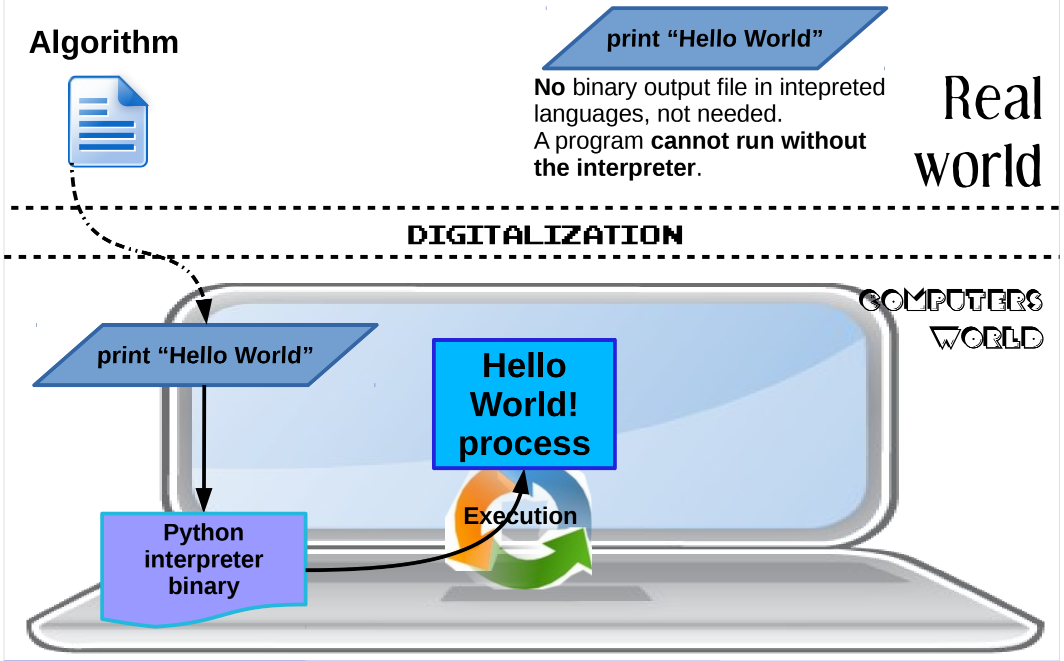
Interpreted languages

- Some languages like Python or PHP have another approach, where compilation **is done on the fly** by an helper compiler process. In this case the compiler process is called **interpreter**.
- The developer can just write a line of code inside the interpreter command line interface and this is **immediately executed**. Compilation is transparent.
- Example: Write “Hello World” in Phyton:
  - Run the python interpreter

    ```
    python
    Python 2.4.3 (#1, Jun 18 2012, 09:40:07)
    [GCC 4.1.2 20080704 (Red Hat 4.1.2-52)] on linux2
    Type "help", "copyright", "credits" or "license" for more information.
    ```
  - Execute a python command

    ```
    >>> print "hello world"
    hello world
    >>>
    ```
- The source code in this case is a **list of commands** to be *passed* to the interpreter to be executed.
  Example:
  ```
  python mysourcecode.py
  ```
- Question: what about BASH from the Tutorials? Discuss.

Steps to interpretation: Python



No binary output file in intepreted languages, not needed.
A program **cannot run without the interpreter**.

Compiled VS Intepreted

	Compiled	Interpreted
Performance	High	Low
Coding Complexity	High	Low
Portability	Low	High
Learning Curve	High	Low
Performance Tuning	Very High	Very Low
Capacity requirements	Very Low	Very High

Compiled, use if:
- Need performance on intensive calculations
- Require specific technologies
- Small devices with limited memory or cpu

Intepreted, use if:
- Need to quickly create a prototype
- Require easy portability on different platforms
- Only on powerful computers

Compiled vs Interpreted in scientific computation

- Compiled languages are used when in need of **performance**, **precision** or **optimization**:
  - machine-consuming tasks that require lots of memory and time, to minimize memory and cpu consumption:
    - Intensive computation (when it takes days or weeks to obtain a result)
    - Complex simulation models (montecarlo, data reconstruction)
    - Parallel computing
  - Dedicated hardware tasks:
    - To take such hardware features to the limit
  - Dedicated hardware with limited resources:
    - Detectors
    - Mobile phones
    - Embedded devices
- Interpreted languages are used for **tedious tasks** that are not going to be executed too frequently, and **quick development**:
  - Submission of multiple computing jobs with multiple parameters
  - Creation of quick proof-of-concept prototypes
  - Streamlining/orchestration of complex computing tasks carried on with compiled languages binary code
  - Scripts that cannot be easily written in BASH.

Bytecode-based languages

- Some languages like Java have an intermediate representation called **bytecode**.
- Bytecode is some sort of compiled code that cannot be executed by a real machine, but by a **Runtime Virtual Machine**. (NOTE: it is NOT like the virtual machine we saw in tutorials!).
- A **Runtime Virtual Machine** is a program that takes in *input* a bytecode file and *translates* it into a real machine binary code.
- The developer must:
  - Compile her *source code* to bytecode

    Example: generate bytecode file from source

    ```
    javac mysourcecode.java
    ```

    Output will be a `musourcecode.class` bytecode file

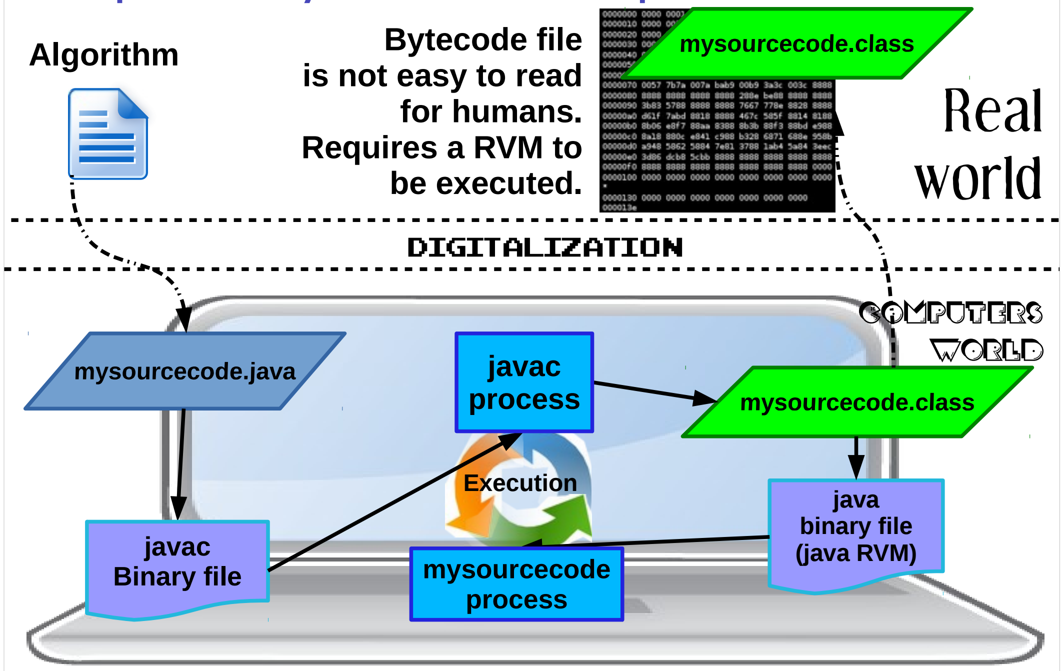
1) *Pass* the bytecode as *input file* to a *runtime virtual machine* for it to run.

   Example: execute a generated bytecode file

   ```
   java mysourcecode.class
   ```

   The RVM will be started and the execution of the program will start.

Steps to bytecode compilation: Java



Dream and reality of Java

- Java's bytecode and Virtual Machine goal was to create a **type-safe**, object oriented **portable** language.
- **Type-safe**: means that the languages always enforces that data types are correct. This is also done by requesting the programmer to take care of eventual bad situations at compile time. This has actually been achieved; but if the programmer fails to do that the code dies badly.
- **Portability**: Bytecode was an attempt to **decouple the physical machine from the computation model**. Unfortunately, in the end the Virtual Machine must “talk” with the actual machine, and that's where portability **failed**.
  - **Different versions of the virtual machine** for Windows, Linux and Mac, not always compatible. Moreover, there are **different implementations** of the JavaVM that are not always compatible
  - **Software Development Kit changes all the time,** making it impossible to write an application that can work with a newer version of the virtual machine. One needs to update both the libraries and the VM.
  - **Efficiency drop**: The virtual machine is usually slower than the real machine; Automatic garbage collection (that allows the programmer not to care about memory problems) causes high memory consumption and makes this language **a bad choice for intensive scientific computation – performance will quickly drop and one will need more powerful hardware.**

Comparison between languages and when they work best

- Every language is usually designed for a specific purpose, and then extended to serve other purposes.
- Sometimes a language is to tightly close to its designed purpose that no extension really changes a programmer way of thinking
- Sometimes the practical use of a language goes very very far from the purpose of which it was designed

C

Features:

- Compiled
- Imperative paradigm
- Functions
- Types and type creation
- Memory Pointers
- Based on standards

Preferred use:

- System development
- Embedded devices
- Low-level coding, i.e. hardware drivers
- Performance

Pros:

- Very efficient
- Can directly use Assembly
- Lots of community experience
- Good debugging tools
- Control on the code preprocessor (for efficiency)

Cons:

- Requires deep knowledge of pointers and memory handling – developer has to free memory by herself
- Has high learning curve
- No object oriented approach: if new features need to be added, code needs to be rewritten or revised
- Hard to foresee runtime errors at compile time
- Control on the code preprocessor (hard to debug and understand)

C example

Reading and printing a file to screen

```
/*
 * readmovies.c
 *
 * Copyleft 2014 Florido Paganelli
<florido.paganelli@hep.lu.se>
 *
 */

// standard library to allocate memory
#include <stdlib.h>
// input/output library
#include <stdio.h>

int main(int argc, char **argv)
{
    // a sequence of chars will contain the file
      char *filecontents;
    // C doesn't automatically know the size of a file
    long input_file_size;
    // opening the file 1984movies for reading
    FILE * input_file = fopen("1984movies", "rb");
    // Calculating the size of the file:
    // reach the end of the file
    fseek(input_file, 0, SEEK_END);
    // get the position of the pointer: will give us
how big is the file
    input_file_size = ftell(input_file);
    // go back at the beginning of the file
    rewind(input_file);
    // allocate memory for file contents
    filecontents = malloc(input_file_size *
(sizeof(char)));
    // read the file regardless of newlines
    fread(filecontents, sizeof(char), input_file_size,
input_file);
    // close the file
    fclose(input_file);

    //print the content of the variable
    printf("%s",filecontents);
      return 0;
}
```

C example

Reading and printing a file to screen – compile and execute

Compile:

```
pflorido@tjatte:~> gcc -o readmovies.c.bin readmovies.c
```

Execute:

```
pflorido@tjatte:~> ./readmovies.c.bin
"imdbID","Title","Genre","Director","Country","imdbRating","imdbVotes"
"tt0090030","Ski Country","Documentary, Sport","Warren
Miller","USA","7.2","9"
"tt0090068","Lorca and the Outlaws","Sci-Fi","Roger
Christian","Australia, UK","3.3","172"
"tt0091050","Final Mission","Action, Crime","Cirio H. Santiago","USA,
Philippines","4.5","127"
```

C++

Features:

- Compiled
- Imperative paradigm
- Object oriented paradigm
- Types and type creation
- Templating
- Memory Pointers
- Based on standards

Preferred use:

- System development
- Embedded devices
- Low-level coding, i.e. hardware drivers
- Performance

Pros:

- Very efficient
- Empowers C with objects, allowing extending existing code
- Can directly use Assembly
- Lots of community experience
- Good debugging tools
- Good coding environments
- Control on the code preprocessor (for efficiency)

Cons:

- Requires deep knowledge of pointers and memory handling – developer has to free memory by herself
- Has high learning curve
- Not suitable for fast prototyping
- Hard to foresee runtime errors at compile time
- Control on the code preprocessor (hard to debug and understand)

C++ example

Reading and printing a file to screen

```
/*
 * readmovies.cpp
 *
 * Copyleft 2014 Florido Paganelli <florido.paganelli@hep.lu.se>
 *
 */

// library for basic input/output
#include <iostream>
// library for files stream
#include <fstream>
// library for strings stream
#include <sstream>
// library for strings
#include <string>
// if not specified, the functions belong to the std namespace
using namespace std;

int main(int argc, char **argv)
{
    // create a stream of strings
    std::stringstream filecontents;
    // create an input file stream
      ifstream myfile;
    // open the 1984movies file as a file stream
      myfile.open ("1984movies");
    // if the open was successfull
      if (myfile.is_open())
      {
        // stream the contents of the file inside the string stream
        filecontents << myfile.rdbuf();
      }
    // close the file
      myfile.close();
    // convert the stream to a string
    string contents(filecontents.str());
    // print out the string
    cout << contents;
      return 0;
}
```

C++ example

Reading and printing a file to screen – compile and execute

Compile:

```
pflorido@tjatte:~> g++ -o readmovies.cpp.bin readmovies.cpp
```

Execute:

```
pflorido@tjatte:~> ./readmovies.cpp.bin
"imdbID","Title","Genre","Director","Country","imdbRating","imdbVotes"
"tt0090030","Ski Country","Documentary, Sport","Warren
Miller","USA","7.2","9"
"tt0090068","Lorca and the Outlaws","Sci-Fi","Roger Christian","Australia,
UK","3.3","172"
"tt0091050","Final Mission","Action, Crime","Cirio H. Santiago","USA,
Philippines","4.5","127"
```

Java

Features:

- Bytecode Compiled for a Runtime Virtual Machine (RVM)
- Portable
- Imperative paradigm
- Object oriented paradigm
- Types and type creation
- Templating
- No memory pointers: memory is managed by the RVM

Preferred use:

- Application development
- Cross platform development
- Embedded devices
- High level coding
- Server-Client architectures
- Big projects

Pros:

- Portable, given the RVM can run it
- Objects allowing reuse and extension of existing code
- Developers do not need to care about freeing memory, all is taken care by the RVM *Garbage Collector*
- Lots of community experience
- Very good debugging tools and coding environments

Cons:

- Portability depends on RVM version, in reality is not really achieved; RVM and SDK updates may break code compatibility
- Has high learning curve
- Not suitable for fast prototyping
- Automatic memory management imposes huge memory requirements on the machine: not efficient
- In the last years a lot of security holes have been discovered in the RVM, needs continuous update

Java example

Reading and printing a file to screen

```java
/*
 * readmovies.java
 *
 * Copyleft 2014 Florido Paganelli <florido.paganelli@hep.lu.se>
 *
 */

// import basic input/output java libraries
import java.io.*;
// import java utility Scanner
import java.util.Scanner;

// everything is a class in java
public class readmovies {
    // cause specific file errors in case of problems
     public static void main (String args[]) throws FileNotFoundException, IOException {

        String text = new Scanner( new File("1984movies") ).useDelimiter("\\A").next();
        // try this code
        try {
            // create an output buffer to standard output
            BufferedWriter output = new BufferedWriter(new OutputStreamWriter(System.out));
            // write the content of text on output
            output.write(text);
            // empty the content of standard out to screen
            output.flush();
        }
        // print an error if it fails
        catch (Exception e) {
            e.printStackTrace();
        }
     }
}
```

Java example

Reading and printing a file to screen – compile to bytecode and launch RVM

Compile and generate a class file:

```
pflorido@tjatte:~> javac readmovies.java
pflorido@tjatte:~> ls
1984movies  readmovies.c  readmovies.c.bin  readmovies.class
readmovies.cpp  readmovies.java  readmovies.py  readmovies.sh
```

Launch the Java Virtual Machine and execute the class file:

```
pflorido@tjatte:~> java readmovies
"imdbID","Title","Genre","Director","Country","imdbRating","imdbVotes"
"tt0090030","Ski Country","Documentary, Sport","Warren
Miller","USA","7.2","9"
"tt0090068","Lorca and the Outlaws","Sci-Fi","Roger Christian","Australia,
UK","3.3","172"
"tt0091050","Final Mission","Action, Crime","Cirio H. Santiago","USA,
Philippines","4.5","127"
```

Python

Features:

- Interpreted
- Portable
- Imperative paradigm
- Object oriented paradigm
- Not typed
- Templating
- No memory pointers: memory is managed by the interpreter

Preferred use:

- Scripting
- Application prototype development
- Cross platform development
- Very High level coding

Pros:

- Portable, given one has the same verison of the interpreter
- Objects allowing reuse and extension of existing code
- No need to care about freeing memory, locations are cleared by Python Garbage Collector
- Lots of community experience
- Very low learning curve
- Very intuitive approach
- Can use C/C++ code

Cons:

- Portability depends on interpreter version
- Automatic memory management imposes huge memory requirements on the machine: not efficient
- Enviroment and scope models not very intuitive, runtime behaviour might be unexpected
- Lack of types might cause unexpected results
- Semantic not well defined: references, pointer like datatypes, can be hard to see looking at the code

Python example

Reading and printing a file to screen

```python
#!/usr/bin/env python
# -*- coding: utf-8 -*-
#
#  readmovies.py
#
#  Copyleft 2014 Florido Paganelli <florido.paganelli@hep.lu.se>
#
#
#

def main():
    # open the file as f
    with open('1984movies','r') as f:
        # read the whole contents
        contents = f.read();
    # close the file
    f.close();
    # output the contents
    print contents;
    return 0

if __name__ == '__main__':
    main()
```

Python example

Reading and printing a file to screen – pass to interpreter or run script

Pass the file to the intepreter to be executed:

```
pflorido@tjatte:~> python readmovies.py
"imdbID","Title","Genre","Director","Country","imdbRating","imdbVotes"
"tt0090030","Ski Country","Documentary, Sport","Warren
Miller","USA","7.2","9"
"tt0090068","Lorca and the Outlaws","Sci-Fi","Roger Christian","Australia,
UK","3.3","172"
"tt0091050","Final Mission","Action, Crime","Cirio H. Santiago","USA,
Philippines","4.5","127"
```

Alternatively, since we specified the intepreter in the script, make the file executable and execute the file:

```
pflorido@tjatte:~> chmod +x readmovies.py
pflorido@tjatte:~> ./readmovies.py
"imdbID","Title","Genre","Director","Country","imdbRating","imdbVotes"
"tt0090030","Ski Country","Documentary, Sport","Warren
Miller","USA","7.2","9"
"tt0090068","Lorca and the Outlaws","Sci-Fi","Roger Christian","Australia,
UK","3.3","172"
"tt0091050","Final Mission","Action, Crime","Cirio H. Santiago","USA,
Philippines","4.5","127"
```

Bash

Features:

- Interpreted
- Runs commands, executables
- Imperative paradigm
- Not explicitly typed
- No memory pointers: only environment

Preferred use:

- Scripting
- Automation of command tasks
- Combine several commands

Pros:

- Use existing commands to do tasks
- Lots of community experience
- Very low learning curve
- Very intuitive approach

Cons:

- Not portable; code depends on installed software
- Lack of types might cause unexpected results
- No memory management, only environment variables might cause scope issues: all variables are global!
- Not rich in native datastructures, that are hard to use and very rarely used in practice

Bash example

Reading and printing a file to screen – executing the script

```
#!/bin/bash
# script readmovies.sh
#

FILECONTENTS=$(cat 1984movies)
echo "$FILECONTENTS"
```

Make the script executable and run it:

```
pflorido@tjatte:~> chmod +x readmovies.sh
pflorido@tjatte:~> ./readmovies.sh
"imdbID","Title","Genre","Director","Country","imdbRating","imdbVotes"
"tt0090030","Ski Country","Documentary, Sport","Warren
Miller","USA","7.2","9"
"tt0090068","Lorca and the Outlaws","Sci-Fi","Roger Christian","Australia,
UK","3.3","172"
"tt0091050","Final Mission","Action, Crime","Cirio H. Santiago","USA,
Philippines","4.5","127"
```

Golden rules of a scientific programmer

(1) Never trust the computer, but trust your scientific intuition

- Remember the digitalization problem: a computer reduces precision

(2) Keep your code simple and functionalities separate in your code

- Write and test each functionality
- Will help you figure out what is wrong

(3) Write many (significant) comments

- Science is knowledge sharing: others will read your code sooner or later

(4) Don't blame the sysadmin until you're sure it's his/her fault! ;-)

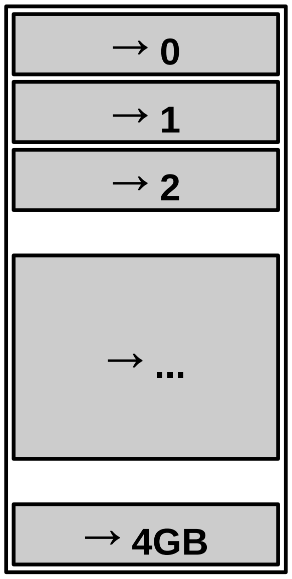
Additional Material

Accessing Memory

- Memory size
- Addressing memory: pointers
- Relative relocation
- Stack
- Heap

Addressing memory (RAM)

- Computer memory is divided in a certain number of **locations**.
- A location is a memory space identified by a **memory address**
- A memory address is a in integer **number**.
- This number is usually called **pointer** (→), as it points to a memory location.



Addressing memory and size: bits and bytes

- The size of a RAM memory bank tells how many memory locations can be pointed or **referenced** within that bank of memory.
- This size is measured in **bytes**.
  - 1 byte is made out of 8 bits.... what does this mean?

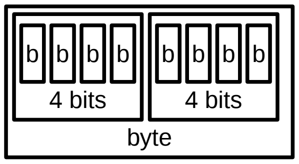
Bits and Bytes

- **A bit** (binary digit) is either 0 or 1. Than means that each bit can represent two integer values: 0 or 1.
- **Two bits** can represent four integer values: 00= 0 , 01 = 1, 10 = 2, 11 = 3
- So how many values can a **byte (8 bit)** represent?
  - 2^8= 256
  - The range is 00000000 – 1111111111, We can represent numbers from 0 to 255 (256 numbers in total)
- If I want to represent at least 1000 values, I need an integer i such that 2^i~1000. For example for i=10, 2^{10}=1024 values, that is, 10 bits can represent 1024 values.
- In modern computer architectures, the 32bit and 64bit buzzword that you frequently hear refers to the size of the **CPU registers**, that is, where the processor copies information from the memory to be processed.
  - A 32bit machine can contain in its registers up to 2^{32} different values.
    - Note: $2^8 * 2^8 * 2^8 * 2^8 = 2^{4*8} = 2^{32}$: A CPU register is made out of 4 bytes!
  - A 64bit machine can contain in its registers up to 2^{64} different values.
    - A register is made out of 8 bytes.

Memory size

- Memory is measured in **bytes**.
- The binary system is used to count the order of magnitude of memory. The reasons are a bit technical and might be explained upon request.
- 1 byte = 8 bits is the fundamental “quantity” of memory information.
- 1024 bytes are called a **Kilobyte**. Often noted as Kb or kb or KB (unfortunately producers never agreed on the notation).
  We will use **KB**.
- Conversion to the different orders is done by dividing/multiplying for 1024 in decimal notation. Examples:
  - 1 KiloByte = 1KB = 1024 Bytes
  - 1 MegaByte = 1MB = 1024 KB = 1048576 Bytes
  - 1 GigaByte = 1GB = 1024 MB = 1048576 KB = 1073741824 bytes
- A 4GB memory bank contains 4*1GB = 4*1024 MB = 4096 MB = 4*1048576 KB = 4194304 KB = 4*1073741824 bytes = 4294967296 bytes

Memory size detailed



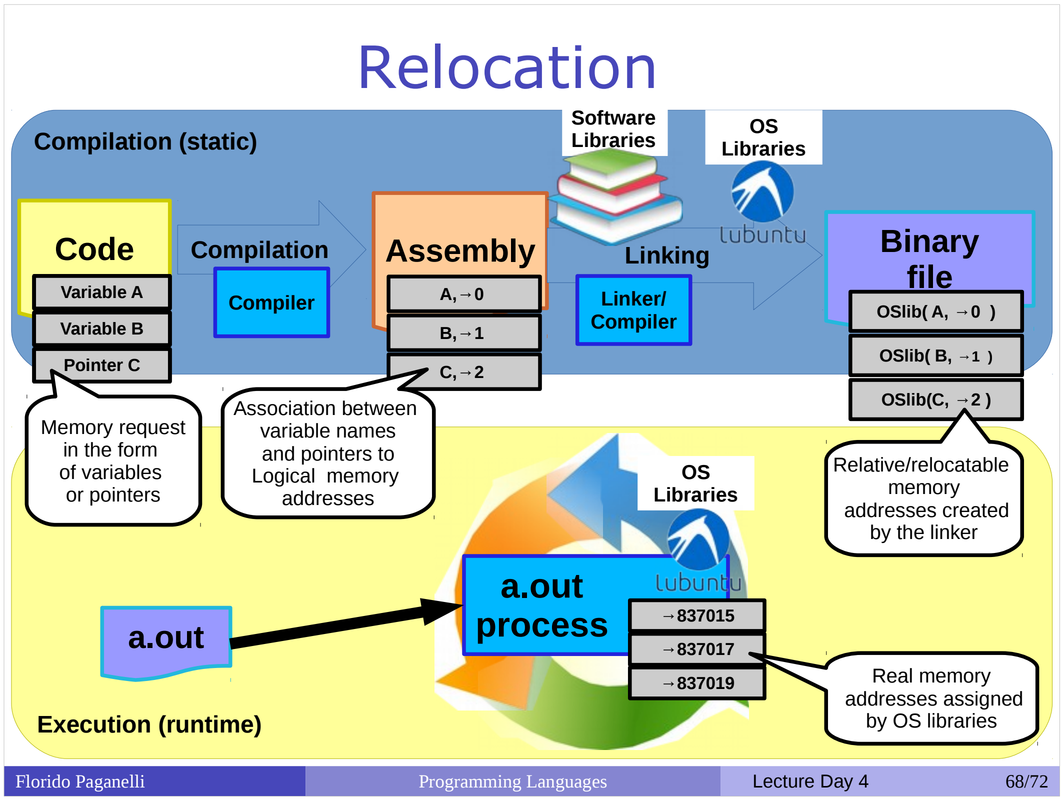
- Memory is measured in **bytes**.
- Since we know how many values we can have in a register made of 32 or 64 bits, it's handy to use the binary system (base 2) to identify the size of a memory bank.
- Byte unit of measure follows the base 2 we presented before. The concept behind this weird choice is historically related to **counting groups of 4 bits**. So:
- 1 byte = 1 byte * 2^0 = **2 groups of 4 bits each**, 2*4 = 8 bits is the fundamental "quantity" of memory information.
- 2 bytes = 1 byte * 2^1 = 4 groups of 4 bits, 4*4 = 2*8 = 16 bits
- 1024 bytes = 1 byte * 2^{10} is called a Kilobyte. Often noted as Kb or kb or KB (unfortunately producers never agreed on the notation). Conversion to the different orders is done by dividing/multiplying for 1024 in decimal notation. Examples:
  - 1 Kilobyte = 1Kb = 2^{10} bytes = 1024 bytes
  - 1 Megabyte = 1Mb = 2^{20} bytes = 1048576 bytes = 1024 KB
  - 1 Gigabyte = 1Gb = 2^{30} bytes = 1073741824 bytes = 1048576 KB = 1024 MB
- A 4GB memory bank contains 4*1073741824 bytes = 4294967296 bytes = 2^{32} bytes = 4194304 KB = 4*1048576 KB = 4096 MB = 4*1024 MB

Addressing memory

- If one wants to address each and every byte in a memory of 4GB, she will need at least 32bits register (why?)
- However, things are not that easy. Not all the represented numbers can be used for referencing memory, see: http://en.wikipedia.org/wiki/3_GB_barrier
- We can anyway assume that the accessible memory space depends on the computer architecture, i.e. a 64bit machine can access 2^{64} memory locations.

Addressing memory

- Observe the following:
  - If I have a big memory, I want a big pointer (64 bit)
  - If I have many pointers, I want to store them in memory
  - Each pointer uses 64bit
- The same application compiled for using 32bit and 64bit memory will be **bigger** when using 64bit pointer.
- Modern 64bit computers just need double the memory of the old 32bit :(



Relocation

- When I write a program, I can access all the memory. But not all the memory is available for users programs, because also the operating system uses it.
- The programmer doesn't want to care about the specific memory address. **He/She just wants some memory!**

Hence:

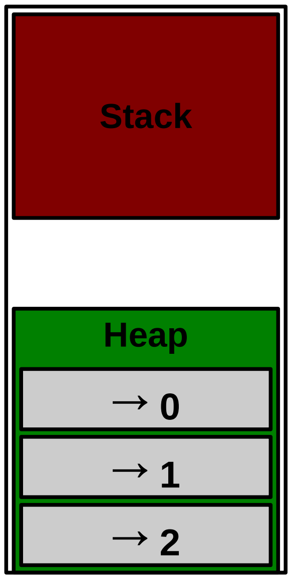
- The developer memory space virtually starts from location 0
- The linker **statically assigns virtual memory addresses** relative to some feature that the operating system offers to the compilation process.
- The Operating System will **dynamically relocate memory addresses** for the program to execute.

Stack and Heap

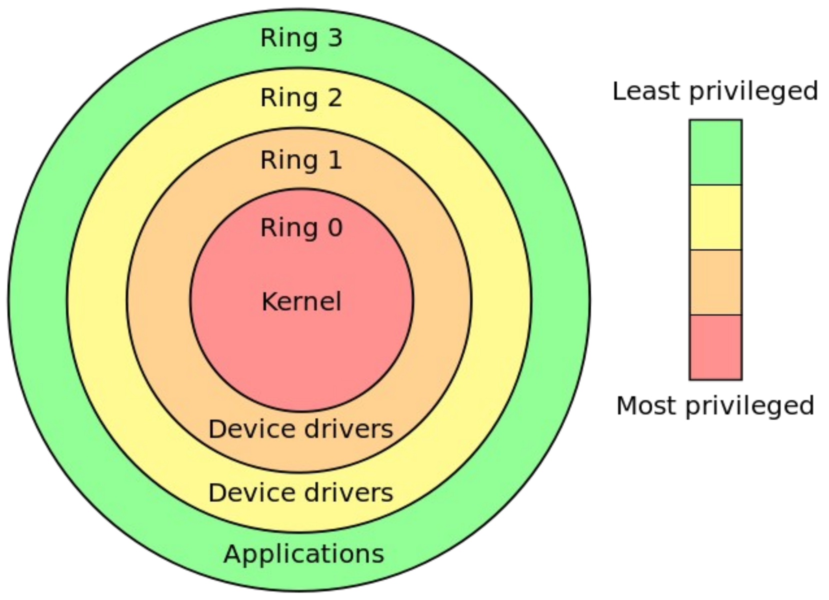
Logical memory available to a programmer can be modeled like partitioned in two sets:

- Stack: Managed by compiler.
  - Memory is allocated and deallocated (freed) automatically by the compiler.
  - It usually only survives for a short term.
- Heap: Managed by developer.
  - developer allocates and deallocates memory by writing explicit programming language statements.
  - **It can survive a whole program if the developer forgets to deallocate it!!**

The use of these will be clearer during the tutorials.



Protection Rings



An operating system is organized such that an application cannot write on the other application's memory.
A **three-layered architecture** where memory access is controlled according to protection rings:

- the core Ring 0 belongs to the kernel, who orchestrates the system. Nobody but the kernel can access its memory
- Ring 1 and 2 are for programs that access the hardware and interact with the kernel directly for performance reasons. Some may write the kernel memory directly, some not.
  - Ring 1, Kernel modules usually write directly
  - Ring 2, Device drivers interact with the modules
- Ring 3, The external layer which is the one where we run our programs.

References

- Binary code:
  http://www3.amherst.edu/~jcook15/binarycode.html
- A brief history of computing
  http://ludwig.lub.lu.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=cat01310a&AN=lovisa.003214669&lang=sv&site=eds-live&scope=site
-

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