Advanced Topics

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Outline

- How to use these slides
- Binary system
- Accessing memory
- Understanding compilation and execution
- Comparison between Bash, C, C++, Python
- Additional material

How to use these slides

- **Build vocabulary**: As a reference whenever you don’t understand what a word mean
- **Review concepts**: whenever a concept is explained during tutorials, bring these along and search for it
- **Future reference**: if anything about computers rings a bell but you don’t remember what it is, check here.

Binary System

How humans count: the decimal system as a language

- Our way of counting numbers is based on the decimal notation. It is called **decimal,** or **base 10** because it is based on **10** basic symbols:
  0 1 2 3 4 5 6 7 8 9
- The decimal **notation** is **positional**. The positions represents powers of the base 10.
  - Each position starting from the rightmost represents a multiplier. Each digit of a number at a certan position is multiplied by the base elevated at a given power. The powers belong to the set of Natural numbers, from right to left, starting from 0.
- Example:
  $2048 = 2*10^3 + 0*10^2 + 4*10^1 + 8*10^0 =$
  $2*1000 + 0*100 + 4*10 + 8*1 =$
  $2000 + 0 + 40 + 8 = 2048$

How computers count: the binary system as a language

- In a computer everything is based on the binary system. That means, the number of symbols of the binary notation is just **2**: 0,1
- The binary **notation** is **positional**. The position represents the powers of the base exactly like the decimal one. The difference is that a binary number can only contain 0 or 1.
- Resolving the powers gives us the **value** of the ***binary number*** as a **decimal number**
- Example:

$$\textit{binary } 1101 = 1*2^3 + 1*2^2 + 0*2^1 + 1*2^0 =$$
$$1*8 + 1*4 + 0*2 + 1*1 =$$
$$8 + 4 + 0 + 1 = 13 \text{ decimal}$$

Why binary?

- Digital circuits are based on mapping **voltage** to **information**
- Measuring voltage can be error-prone, so one must minimize the error
- Years of engineering studies showed that the safest choice is either to have three voltage states or two
- Two proved to be safest and easiest to handle as the number of circuits on a circuit board grows: they interfere with each other! (magnetic fields etc)
- Modern computing sets the voltage difference to be $\mp$5V
- Mapping: $\mp$5V = 0, 0V = 1 (yeah, I know, misleading. But there are practical reasons for it. We don't have to care.)

Mapping things to binary

- In a computer, a sequence of bits contained in a memory chunk can be one of:
  - **Boolean expression** (True/False) or binary string
  - Number or **Value**
  - Operation or **Instruction**

Binary Logic: Boolean Algebra

- Here I describe the so called “first order logic”, where a **preposition** is assigned a **truth value**.
  - We will denote prepositions with capital letters P, Q.
- Only **two** possible **values**:
  - 1 or T as **True**
  - 0 or F as **False**
  - Unfortunately the above is sometimes the opposite for some languages.
- Few **operators**:
  - ¬, **negation**. Unary. Ex: ¬P.
    - Code: usually **!** or **!=**
  - ∧, **AND**, conjunction. Binary. Ex: P AND Q
    - Code: usually **&** or **&&**
  - ∨, **OR**, disjunction. Binary, P OR Q
    - Code: usually | or ||
  - ⇒, **implication**, P ⇒ Q not used in the programming languages we will see in this course.
  - **Parentheses** can be used to compose expressions.

Binary operators: Truth tables

Negation (**NOT**, symbol: ¬), unary: ¬P

P	NOT P
F	T
T	F

NOT (symbol: ¬) **flips** the binary value

Conjunction (**AND**, symbol ∧), binary: P∧Q

P	Q	P AND Q
F	F	F
F	T	F
T	F	F
T	T	T

P AND Q = 1 ONLY when BOTH P,Q = 1

Disjunction (**OR**, symbol ∨), binary: P∨Q

P	Q	P OR Q
F	F	F
F	T	T
T	F	T
T	T	T

P OR Q = 1 if ANY of P,Q = 1
P OR Q = 0 when BOTH P,Q = 0

Implication (symbol ⇒), binary: P⇒Q

P	Q	P ⇒ Q
F	F	T
F	T	T
T	F	F
T	T	T

⇒ = 0 if and only if P = 0
ex falso (sequitur) quodlibet
"from falsehood, anything (follows)"
Should ring a bell about fake news.

Binary operators in coding: Truth tables

Negation (**NOT**, symbol: **!**), unary: **!**P

P	!P
0	1
1	0

! *flips* the binary value
The comparison operator for ≠ , different, is often written as *not equal* in programming languages: **!=**
The equal operator is often written as **==**

Conjunction (**AND**, symbol **&&**), binary: P && Q

P	Q	P && Q
0	0	0
0	1	0
1	0	0
1	1	1

P && Q == 1 ONLY when BOTH P,Q == 1

Disjunction (**OR**, symbol **||**), binary: P || Q

P	Q	P || Q
0	0	0
0	1	1
1	0	1
1	1	1

P || Q == 1 if ANY of P,Q == 1
P || Q = 0 when BOTH P,Q == 0

Implication in not used in the programming languages we will study.

Boolean algebra

- **NOT** *flips* values and operators:
  !(P && Q) == !P || !Q
  !(P || Q) == !P && !Q
  !(!P) == P
- && and || have the following properties: *commutative, associative, distributive* unless otherwise specified.
  - In some programming languages the evaluation might stop depending on associativity.
- Notable other operators are defined on top of those, like
  XOR (eXclusive OR):
  P⊕Q = (P && !Q) || (!P && Q) == applying distributive ==
  (P || !P) && (P || Q) && (!Q || !P) && (!Q || Q) ==
  T && (P || Q) && (!Q || !P) && T ==
  (P || Q) && (!Q || !P) == (P || Q) && (!P || !Q) ==
  (P || Q) && !(P && Q)

Binary logic: XOR an XNOR

P	Q	P XOR Q	XNOR !(P XOR Q)
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

XOR = 1 if P,Q differ
! XOR = 1 if P,Q have exactly the same value

Most programming languages provide a specific operator for XOR...

Note: Usually **==** or **!=** are different from XOR **because they're not binary – they can compare much more than just binary strings.** But XOR might be used behind the scenes in the circuits.

Information as a binary mapping: Memory, Bits and Bytes

- The fundamental unit of measure of information is the **bit** (**bi**nary digi**t**): either **0** or **1**.
- Assume a fundamental memory component of a circuit can store exactly one bit. That means, that component can be used to represent two decimal integer values: 0 or 1, depending on its voltage status.
- Two memory components can represent **two bits**. If we consider them ordered as in the binary notation, we can represent up to **four integer values** as in the table. That is, with **2 bits** we can represent $\mathbf{2^2}$ different values. This can be generalized, **n bits** represent $\mathbf{2^n}$ values.

Binary	Decimal
00	0
01	1
10	2
11	3

- The **value** in decimal is called ***magnitude*** of a sequence of bits.
- For historical reasons, an **ordered group of 8 bit** is used as the fundamental unit of measure of computer memory. This is called a **byte**.
  - How many different integer values can a **byte (8 bit)** represent?
    - The range is 00000000 – 11111111, We can represent numbers from 0 to 255 (256 numbers in total)
    - In other words, $2^8 = 256$

Information as a binary mapping: Memory, Bits and Bytes

- If I want to represent at least 1000 values,
  I need an integer **i** such that $2^{i} \sim 1000$.
  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. I will present it later.
  - 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.
    - In a 64 bit machine a register is made out of **8** bytes.

Digitization of information

Real world

COMPUTERS' WORLD

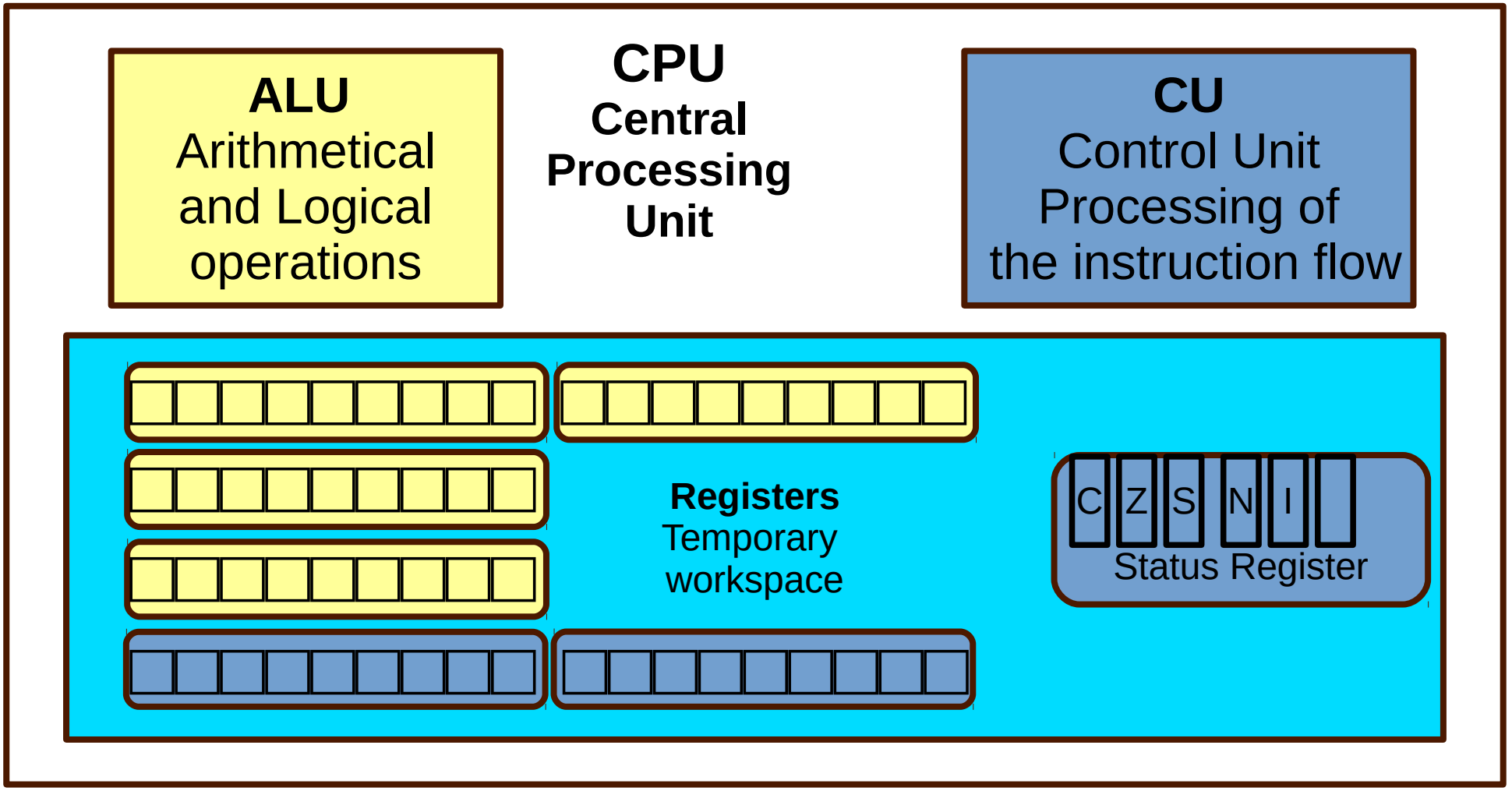
Digital circuits are discrete (countable)

- **Digitization** is the process of transforming what is continuous into something **discrete** with electronic devices.
- A dreadful consequence of having a finite set of countable memory components representing information is that **there is a finite set of numbers we can represent.**

Problems:

- What happens when the result of an operation **exceeds the finite representation** space?
- How do one represents **negative** numbers?
- How do we represent **fractions**/**irrational** numbers/**periodic** numbers/**complex** numbers?
- How do we represent the concept of **infinity**?

Arithmetic in a CPU

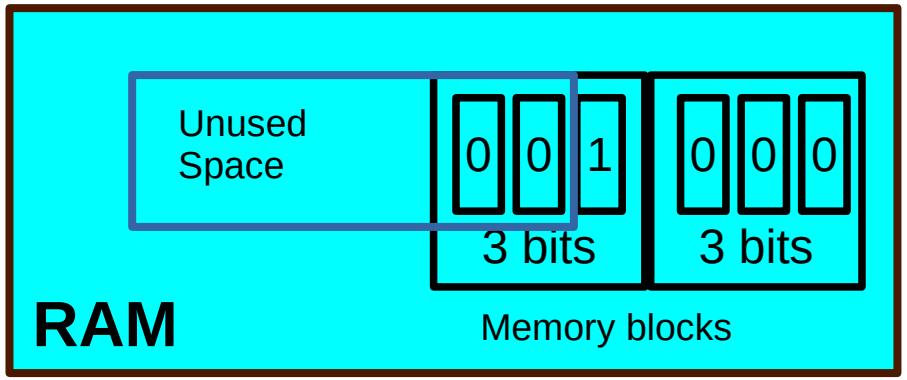


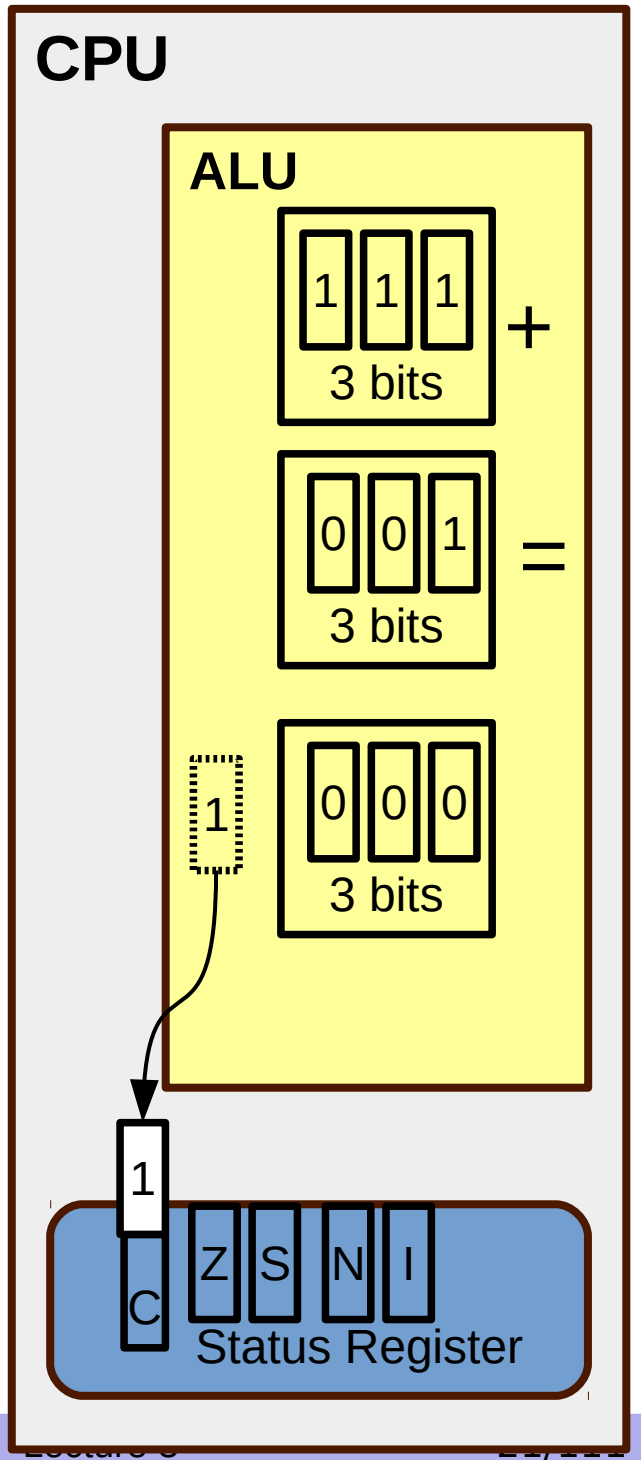
Arithmetic in a CPU

- **ALU**, Arithmetical and Logic Unit does most of the calculations
- **CU**, Control Unit, coordinates the flow of calculations
- Inside the CPU there are dedicated **registers**, memory components, assigned either to ALU or CU
  - An additional **Status Register** is used for both flow and calculations

Limitations of finite representation: addition

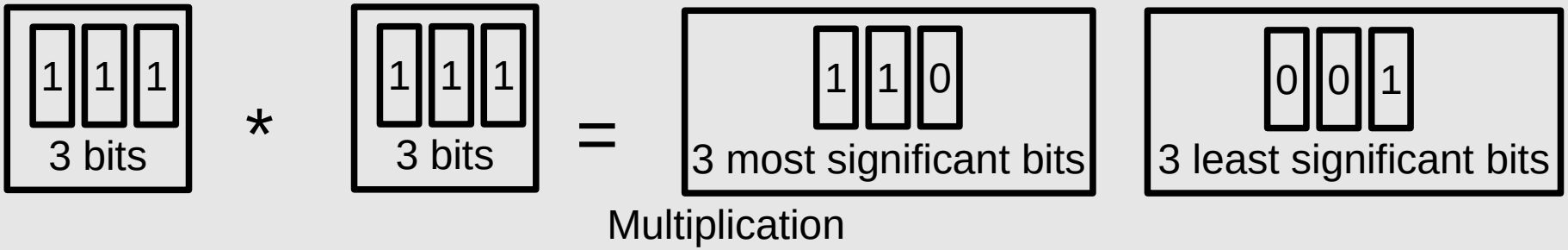
- **Carry overflow** and **register reset**: imagine we have only 3 bit registers (numbers from 000 to 111):
  - 111 + 001 = 1000 = 1 carry and 000 but:
    our registers can only contain 000.
    - Need to keep info about carry somewhere (usually special **carry bit** in the arithmetic circuitry).
    - Need to store the result in **two** memory blocks.



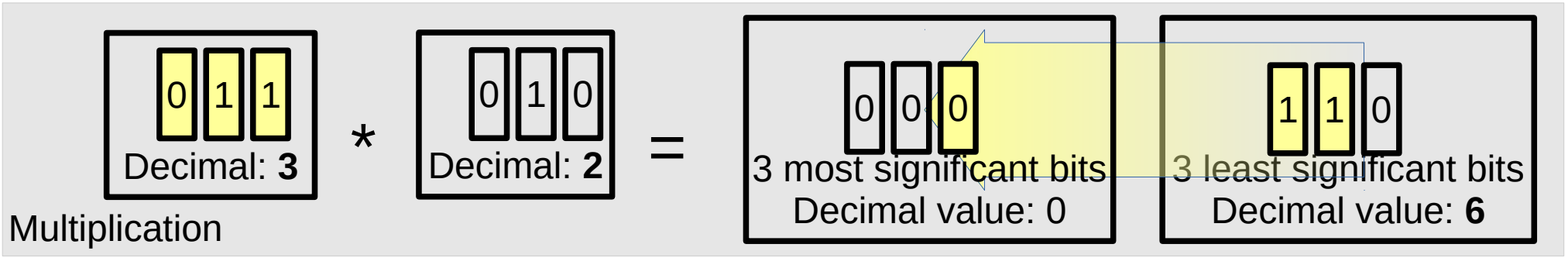


Limitations of finite representation

- Multiplication requires double the size:
  - 111 * 111 = 110001 : it's **6** bits!
    - Need to manage multiplications in a special way.



- Property: multiplication/division by 2 is a *shift left* (multiplication) or *shift right* (division with no remainder)

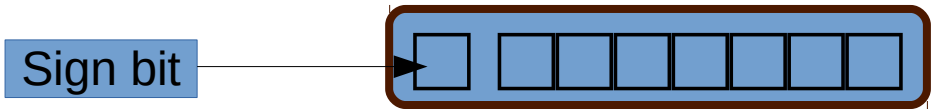


Limitations of finite representation

- Circuits for computation are different from our way of counting:
  combinations of adders and shifters to achieve all operations
- In general, one must be **very careful** when doing calculations **at the edge of the possible representations**:
  Digitization of continuous data leads to **loss of information** if at the edge of the representable values.
  - Example: how to represent negative numbers? Is using one bit for the sign a solution? Discussion.

Integers

- 2- complement representation



8 bit registers example

+127	0 1 1 1 1 1 1 1
0	0 0 0 0 0 0 0 0
-128	1 0 0 0 0 0 0 0

- The most significant bit (msb) is the **sign bit**, with value of 0 representing positive integers and 1 representing negative integers. **This alone is not enough and dangerous!**
  - 00000000 = 0 and 1000000 = -0, an arithmetic with two zeros? Also, we lose one possible representable number.

Enters **complement representation**:

- **Complement** is the operation of flipping a binary value (a sequence of **NOT**):
  complement_of(1) = 0 complement_of(0) = 1
- The remaining n-1 bits represent the **magnitude** of the integer, as follows:
  - for positive integers, the absolute value of the integer is equal to "the magnitude of the (n-1)-bit binary pattern".
  - for negative integers, the absolute value of the integer is equal to "the **magnitude** of the complement of the (n-1)-bit binary pattern plus one" (hence called 2's complement).
    - Example: **-**128 = 10 00 00 00 = **-** [magnitude_of (complement_of(0 00 00 00)) + 1] = **-** [magnitude_of (1 11 11 11) + 1] = **-** [127 + 1] = **-**128

From: https://personal.ntu.edu.sg/ehchua/programming/java/DataRepresentation.html

Integers

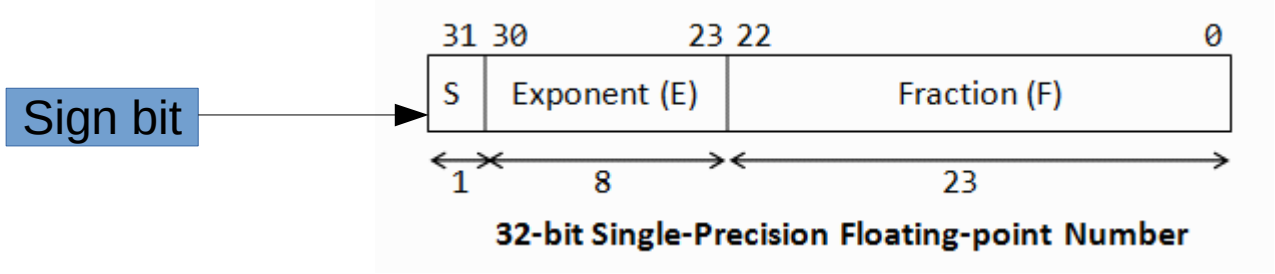
- 2- complement representation limits

Size of registers	minimum	maximum
8	-(2^7) (=-128)	+(2^7)-1 (=+127)
16	-(2^15) (=-32 768)	+(2^15)-1 (=+32 767)
32	-(2^31) (=-2,147,483,648)	+(2^31)-1 (=+2,147,483,647) (9+ digits)
64	-(2^63) (=-9,223,372,036,854,775,808)	+(2^63)-1 (=+9,223,372,036,854,775,807) (18+ digits)

From: https://personal.ntu.edu.sg/ehchua/programming/java/DataRepresentation.html

Real numbers

- IEEE-754 32-bit Single-Precision Floating-Point Numbers

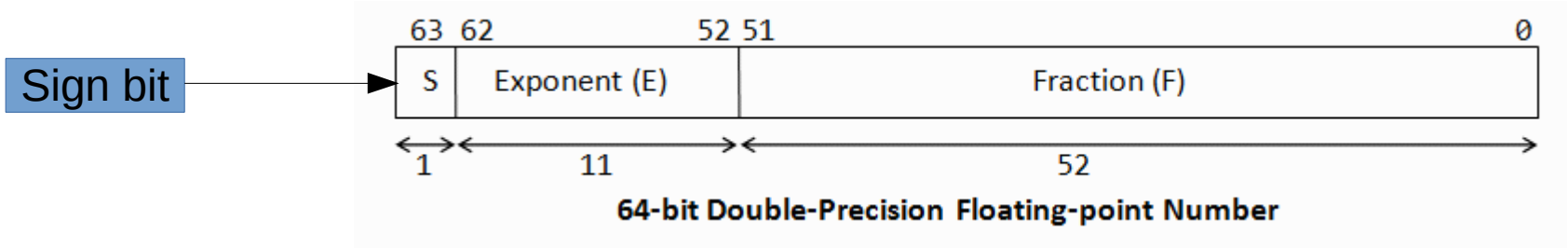


- For **1 ≤ E ≤ 254**, $N = (-1)^S \times 1.F \times 2^{(E-127)}$. These numbers are in the so-called **normalized** form.
  - The sign-bit represents the sign of the number.
  - Fractional part (1.F) are normalized with an implicit **leading 1**.
  - The exponent is bias (or in excess) of 127, so as to represent both positive and negative exponent. The range of exponent is -126 to +127.
- For **E = 0**, $N = (-1)^S \times 0.F \times 2^{(-126)}$. These numbers are in the so-called **denormalized** form.
  - The exponent of $2^{(-126)}$ evaluates to a very small number.
  - Denormalized form **is needed to represent zero** (with F=0 and E=0). It can also represents very small positive and negative number close to zero.
- For **E = 255**, it represents special values, such as **±INF** (positive and negative infinity) and **NaN** (not a number).

From: https://personal.ntu.edu.sg/ehchua/programming/java/DataRepresentation.html

Real numbers

- IEEE-754 64-bit Double-Precision Floating-Point Numbers



- Normalized form:
  For **1 ≤ E ≤ 2046**, $N = (-1)^S \times 1.F \times 2^{(E-1023)}$.
- Denormalized form:
  For **E = 0**, $N = (-1)^S \times 0.F \times 2^{(-1022)}$. These are in the denormalized form.
- For **E = 2047**, N represents special values, such as **±INF** (infinity), **NaN** (not a number).

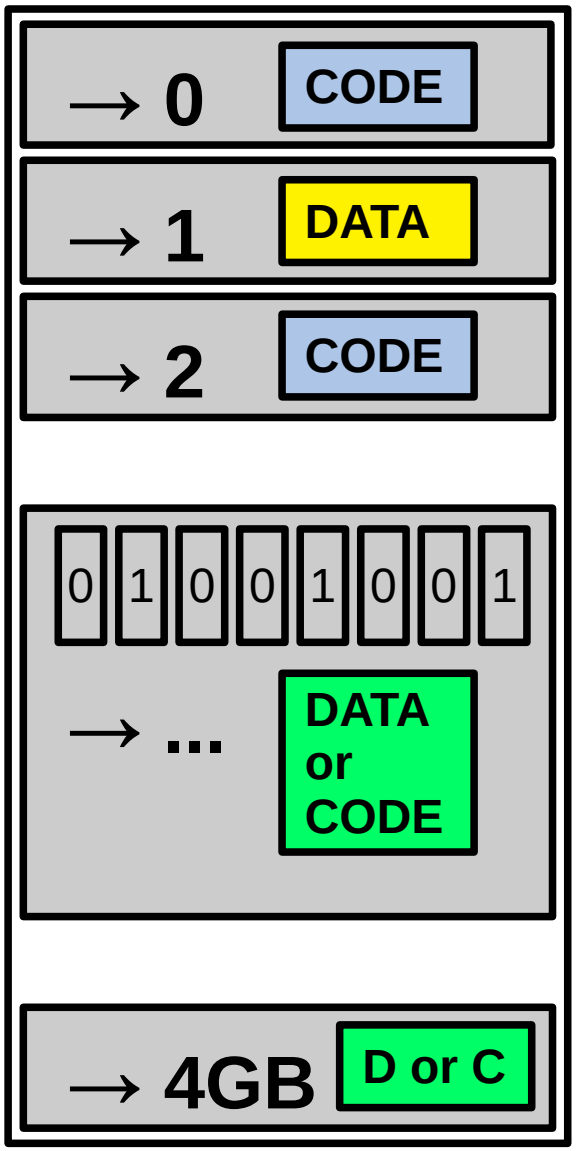
From: https://personal.ntu.edu.sg/ehchua/programming/java/DataRepresentation.html

Computer Memory

- Memory size
- Addressing memory: pointers
- Stack and Heap

Addressing memory (RAM)

- Computer memory is divided in a certain number of **locations**.
- A physical memory element at a specific location is like a register, and has a size in bit.
  Usually it is 8 bits = 1 byte.
- A location is a memory space identified by a
  memory address
- A memory address is an integer **number**.
- This number is usually called **pointer** (→), as it points to a memory location.



Useful bases for memory

- Octal: 0 1 2 3 4 5 6 7
  - Decimal 8 = Octal 10
- Hexadecimal:
  - Useful for memory maps (hex-editors)

Decimal	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hex	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

  - Decimal 16 = Hexadecimal 10 = $1*16^1 + 0 * 16^0$

Memory map

Memory map	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0								7 hex 7 dec								0F hex 15 dec
1																1F hex 31 dec
2								27 hex 39 dec								
3																
4																
5																

One can identify memory locations using the hexadecimal system so to get a table view instead of sequential.

Addressing memory and size: bits and bytes

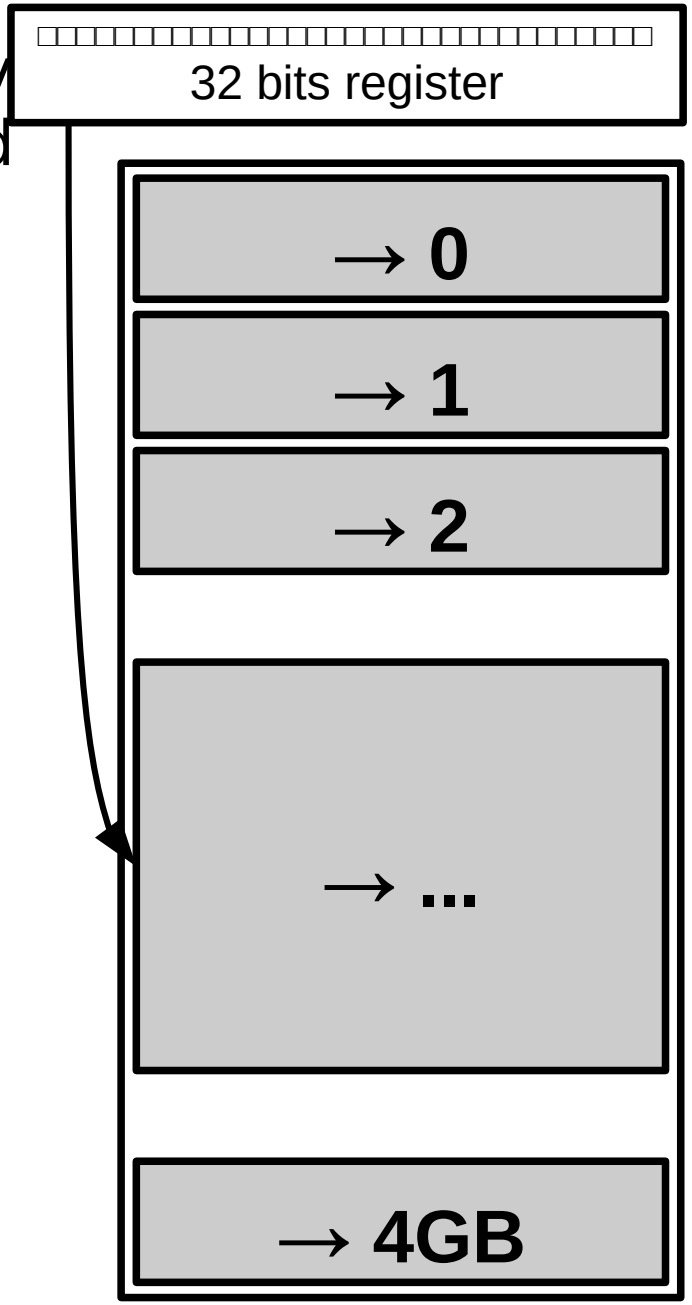
- The size of a RAM memory bank tells how many memory locations can be **pointed** or **referenced** within that bank of memory.
- This size is measured in **bytes**.
  - Remember: 1 byte is made out of 8 bits
- 1024 bytes are called a **Kilobyte**. Often noted as Kb or kb or KB (unfortunately producers never agreed on the notation). We will use **KB**.

Memory size

- Conversion to the different orders is done by dividing/multiplying for **1024** in decimal notation. Examples:
  - 1 KiloByte = 1 KB = 1024 Bytes
  - 1 MegaByte = 1 MB =
    1024 KB =
    1 048 576 Bytes
  - 1 GigaByte = 1 GB =
    1024 MB =
    1 048 576 KB =
    1 073 741 824 Bytes = about 1 Billion bytes.
- A 4 GB memory bank contains
  4*1 GB =
  4*1024 MB = 4096 MB =
  4*1048576 KB = 4194304 KB =
  4*1073741824 Bytes = 4 294 967 296 Bytes

Addressing memory: pointers

- If one wants to address each and every byte in a memory of 4GB, she will need at least 32bits register:
  - **4GB** = 4 billions memory locations = 4096MB = 4 294 967 296 = $\mathbf{2^{32}}$
  - The number contained in the register is usually called a **pointer,** as it **points** to a memory location
- 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 $\mathbf{2^{64}}$ memory locations (= 16 PB).



Addressing memory: the compromise

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

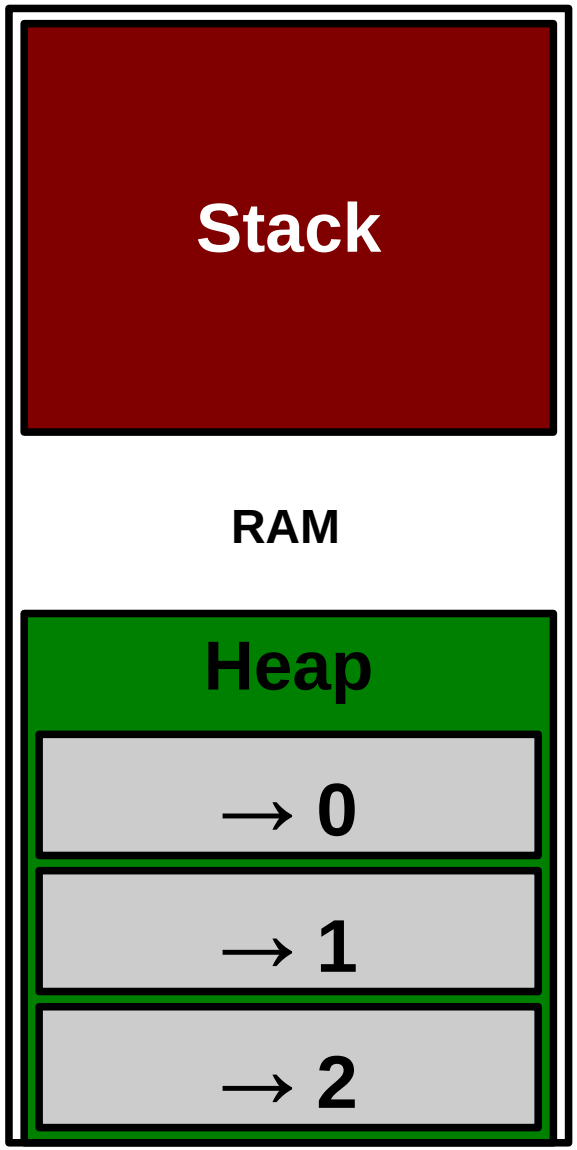
- What is the only benefit?
  - **Bigger memory space**
    - We can actually memorize double the things, provided that we are careful in specifying that we can pack them in a 64 bit space (compilers can do this, but at a cost)
  - **Precision:**
    - We can represent more integer numbers
    - non integer numbers can be more close to the theoretical representation (reducing the approximation error)

Stack and Heap

Modern programming saves you from specifying the exact pointer location. The memory is represented as a **logical memory** available to a programmer.
It is modelled like partitioned in two sets:

- **Stack**: Managed by a tool called **compiler**.
  - Memory is allocated and deallocated (freed) automatically by the **compiler**.
  - It usually only survives for a short term.
  - Function recursion uses that heavily.
- **Heap**: Managed by **developer** directly using system libraries functions.
  - developer allocates and deallocates memory by writing explicit programming language statements.
  - **It can survive after the program has stopped running if the developer forgets to deallocate it!!**

The use of these will be clearer during the tutorials.



From binary to programming languages

How does it work?
The computing cycle (summary)

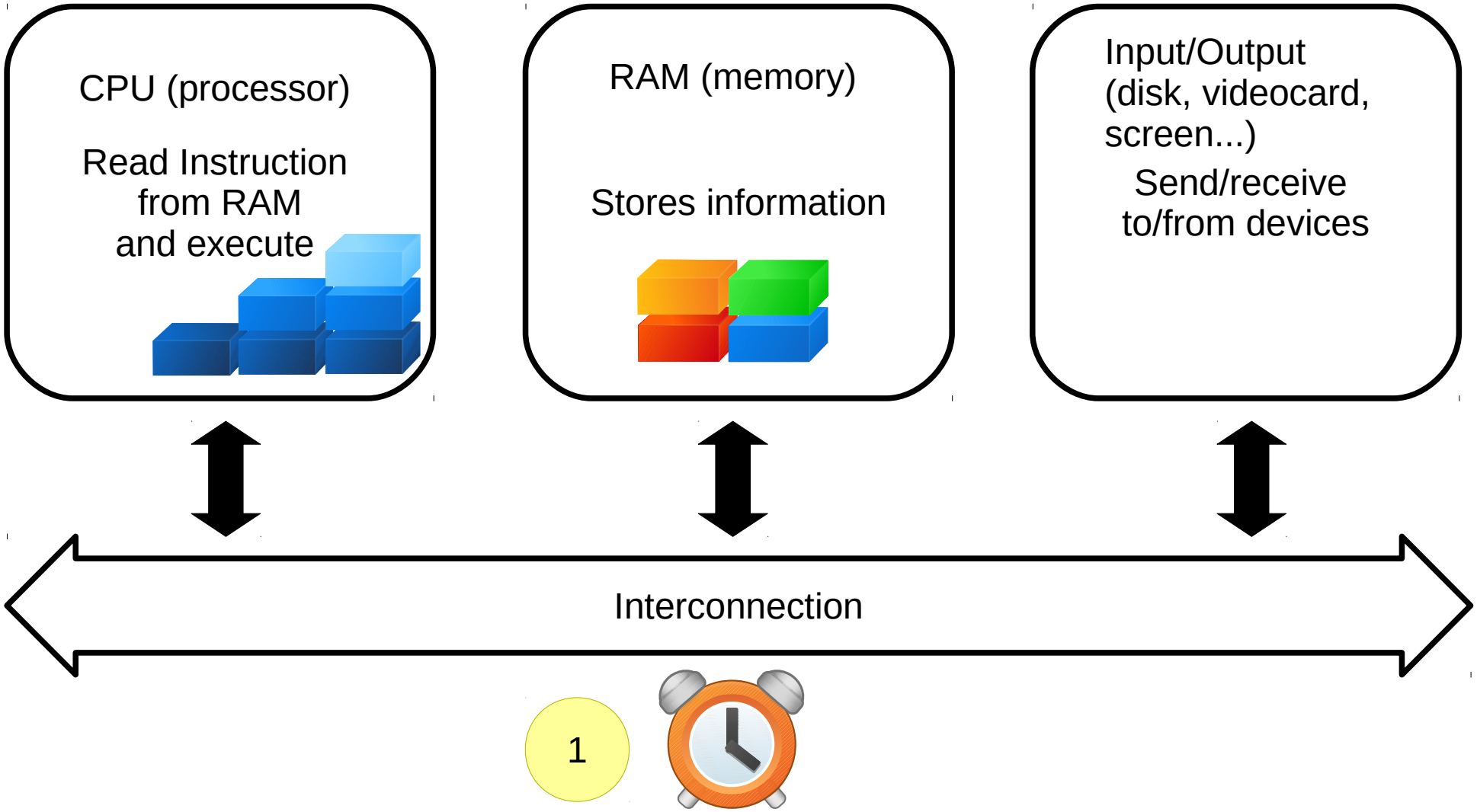
The execution cycle and the clock

1) clock ticks
2) CPU reads content of RAM(instructions) into registers and executes
3) Execution might dispatch information over the bus
4) Wait for next clock cycle.

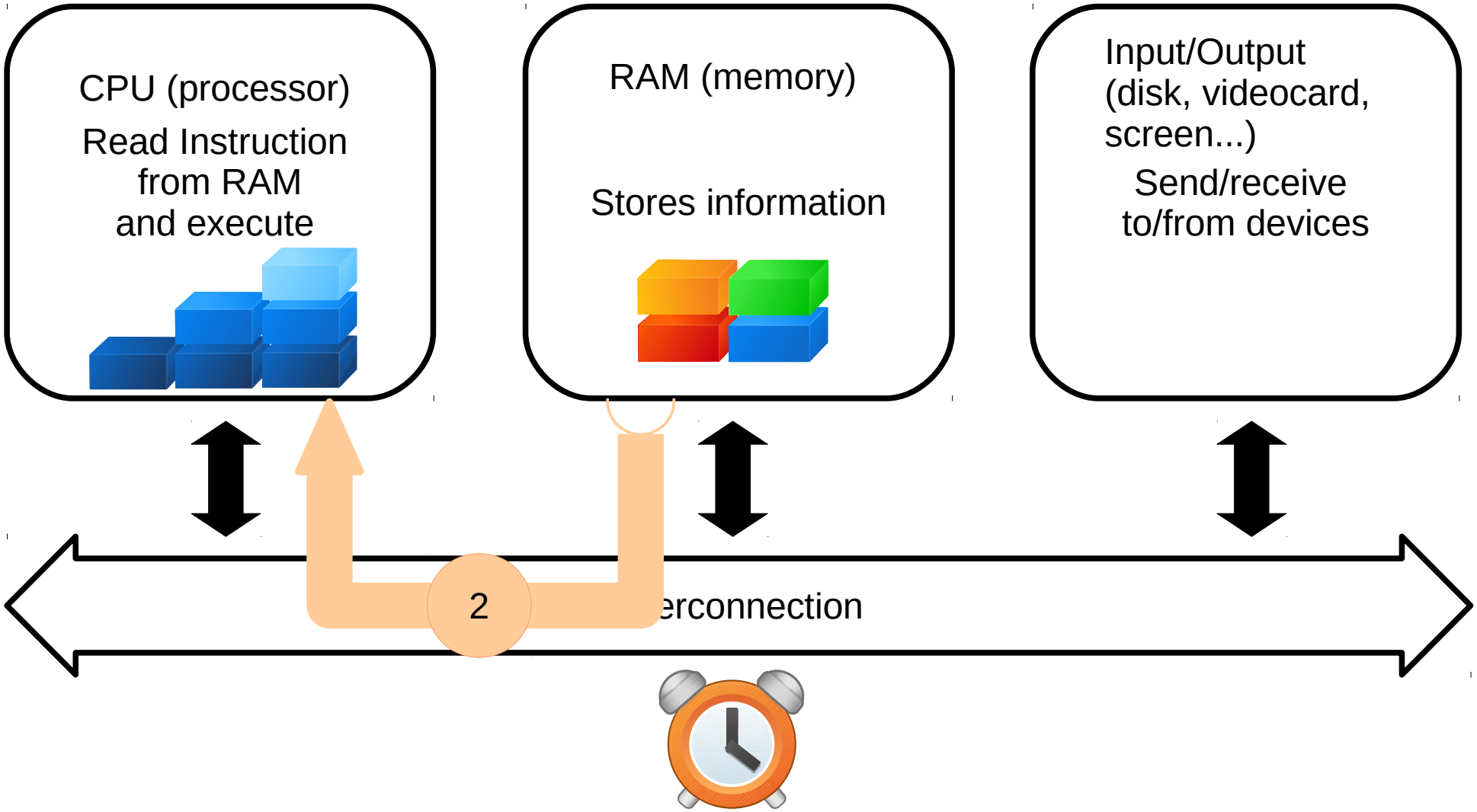
The execution is **always serial**, but gives us a feeling of parallel tasks because of speed.
In modern computers it might require more than one clock cycle to execute a single instruction.

See next slides for a graphical representation.

How does it work?
The computing cycle



How does it work?
The computing cycle



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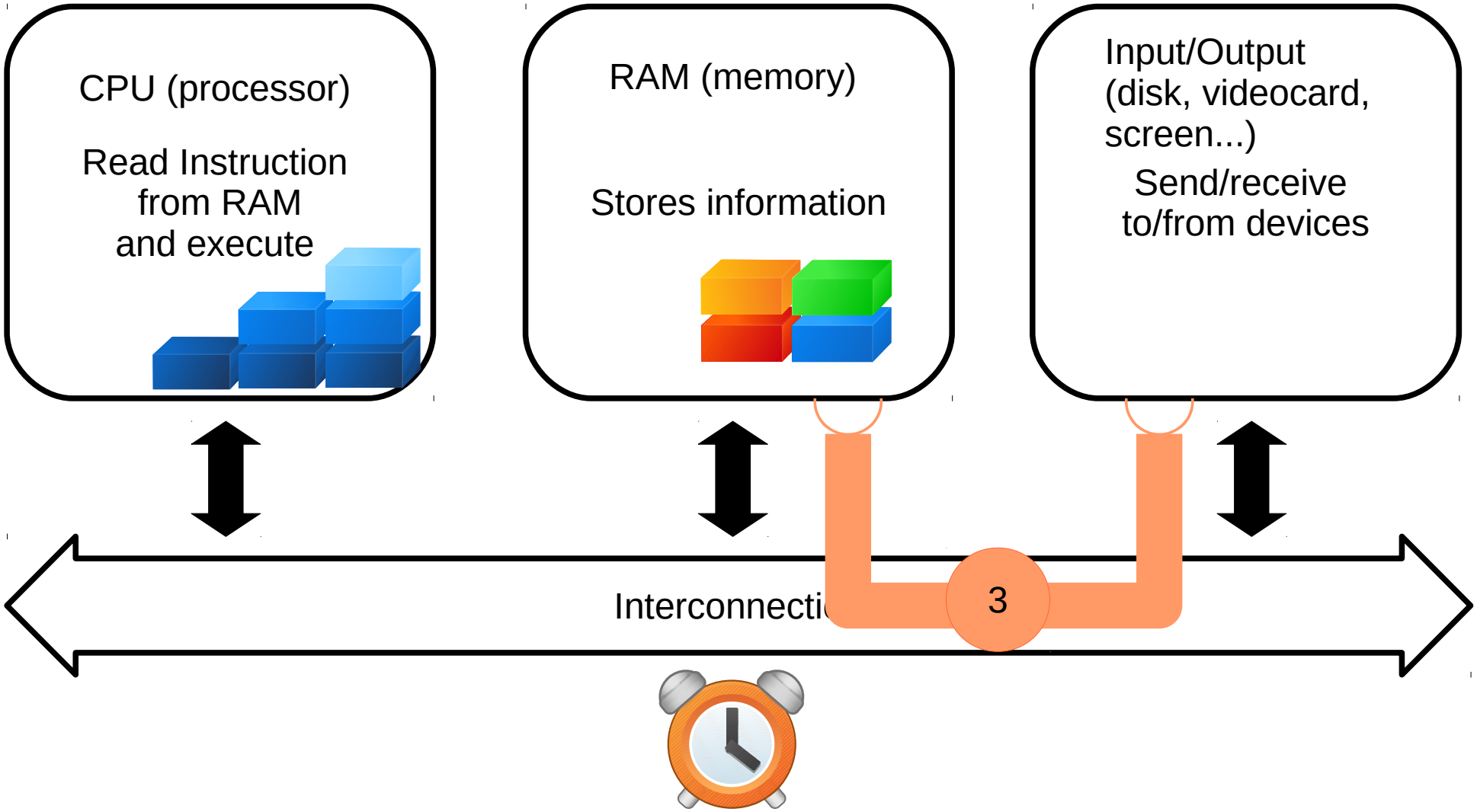
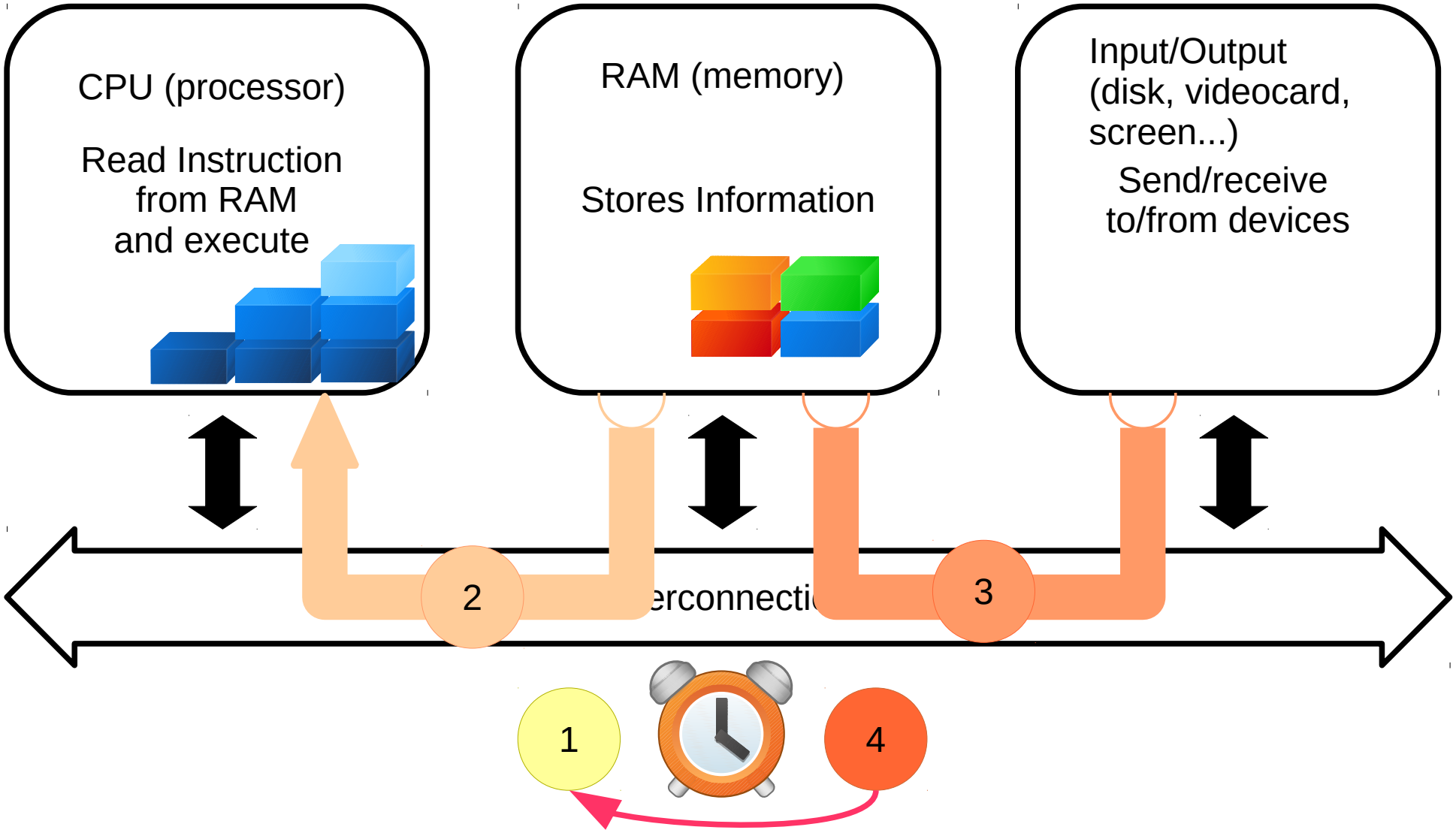


How does it work?
The computing cycle

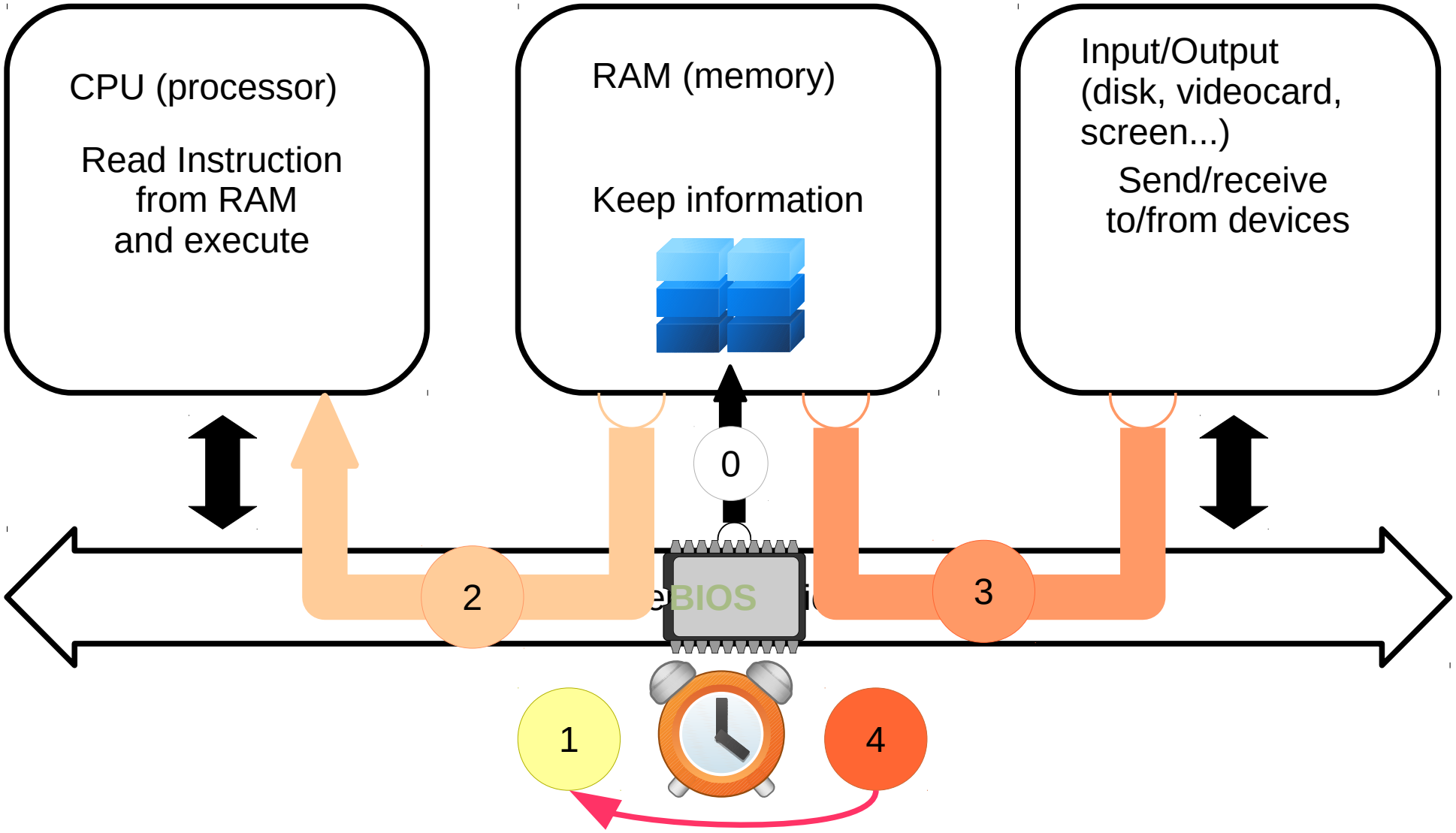


But... How does it start?

- When a computer is turned on, the first thing it does is to **boot**
- **Boot**, or the bootstrap sequence, is a set of operations done in order to start the the computing cycle as described before.
- A small program is copied into the RAM as soon as the computer starts, and this is executed by the machine.
- This program is usually stored in a long term memory chip and is called **BIOS**

But... how does it start?!?

BIOS: Basic Input/Output System
to bootstrap the computer



But... how does it start?!?

BIOS: Basic Input/Output System
to bootstrap the computer

0. The BIOS loads a small program (a set of intructions and the data needed) into the RAM.
When the clock starts, the CPU will start executing as explained.

Binary as machine language

- A machine only has the binary alphabet to describe things. All that moves between the CPU and the Memory is chunks of memory of the maximum size as the number of bits given by the architecture (i.e. 32 or 64 bits)
- These memory chunks can be either data or **instructions,** that is, *words* of the machine language.
- The next program instruction is contained in the RAM and addressed by a memory pointer contained in a special register in the CPU called **Program Counter (PC)**
- When an instruction is copied from RAM to a special register inside the CPU, the **Instruction Register (IR)**, this will be **executed**, the operation that it represents will be carried on.
- The operation may contain other sub-operations that may include moving chunks of memory inside registers or use special features (like virtualization instruction)

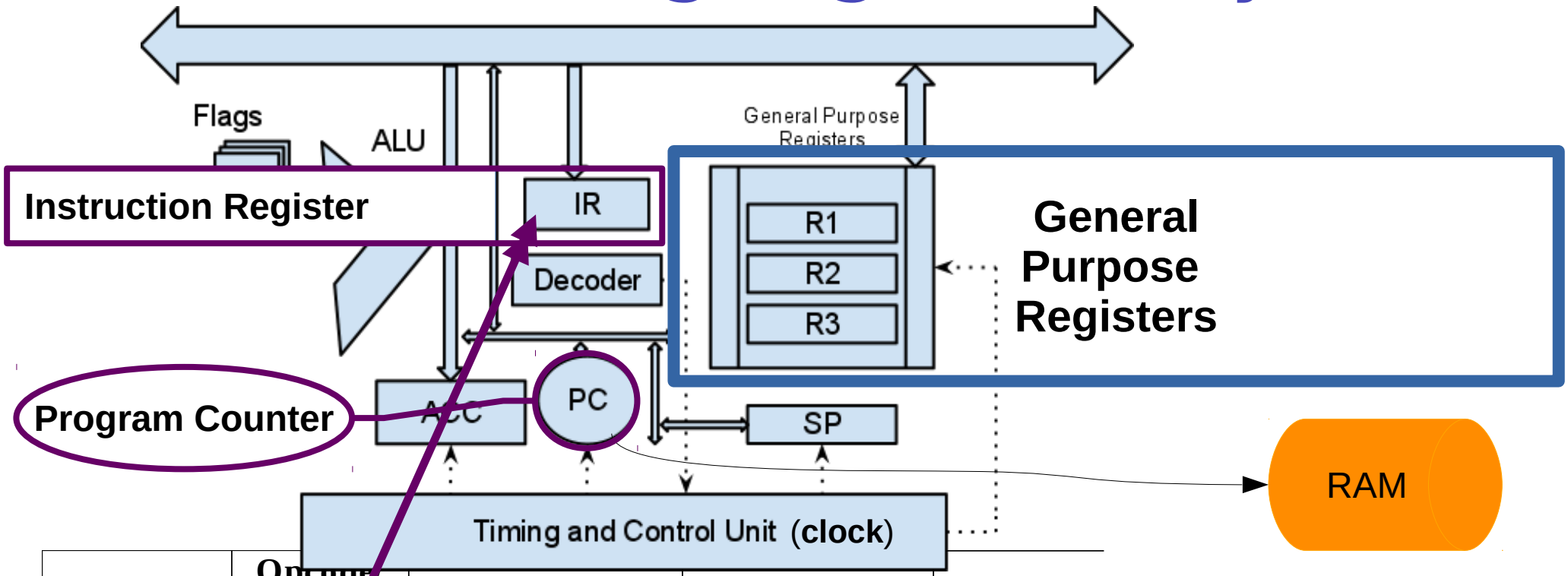
Machine Language: Binary Code

- A computer instruction is a **sequence of bits**, that is, zeroes and ones.
- A binary instruction is also called **opcode**, **Op**eration **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.
- This table is stored inside the CPU, and the set of instructions is also called **microcode** – small code embedded inside the processor.

Instruction	Opcode/ Function	Syntax	Operation	#words
add	100000	ArithLog	$d = $s + $t	1(opcode)
addu	100001	ArithLog	$d = $s + $t	1(opcode)
and	100100	ArithLog	$d = $s & $t	1(opcode)
sto	111100	MemMov	$d → $loc	2(opcode +memloc)
mov	111110	MemMov	$loc → $s	2(opcode +memloc)

$d	ID of destination register
$s	ID of source register
$t	ID of second source register
$loc	Memory location

Machine Language: Binary Code



Instruction	Opcode Function	Syntax	Operation	#words
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$d	ID of destination register
$s	ID of source register
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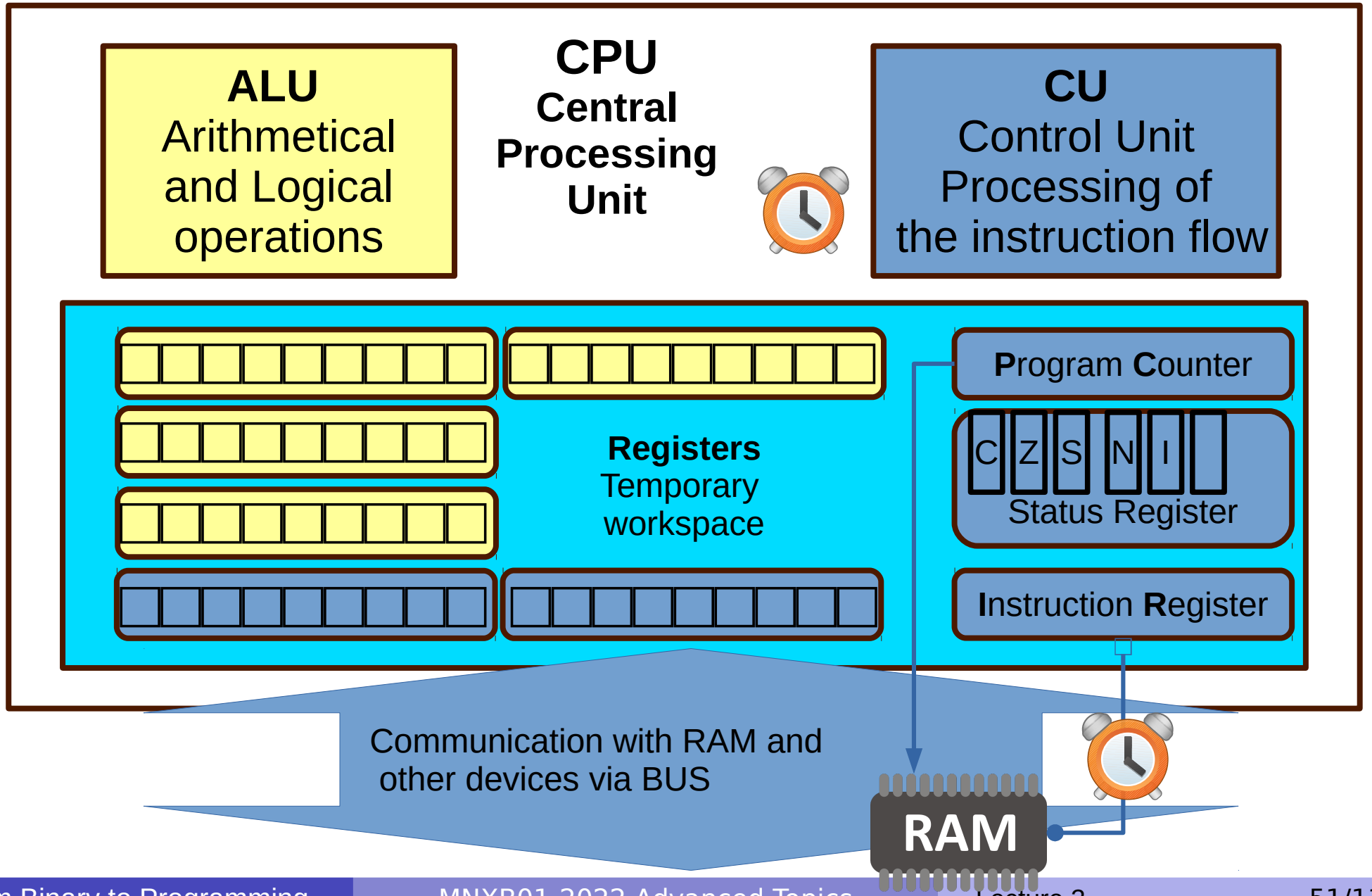
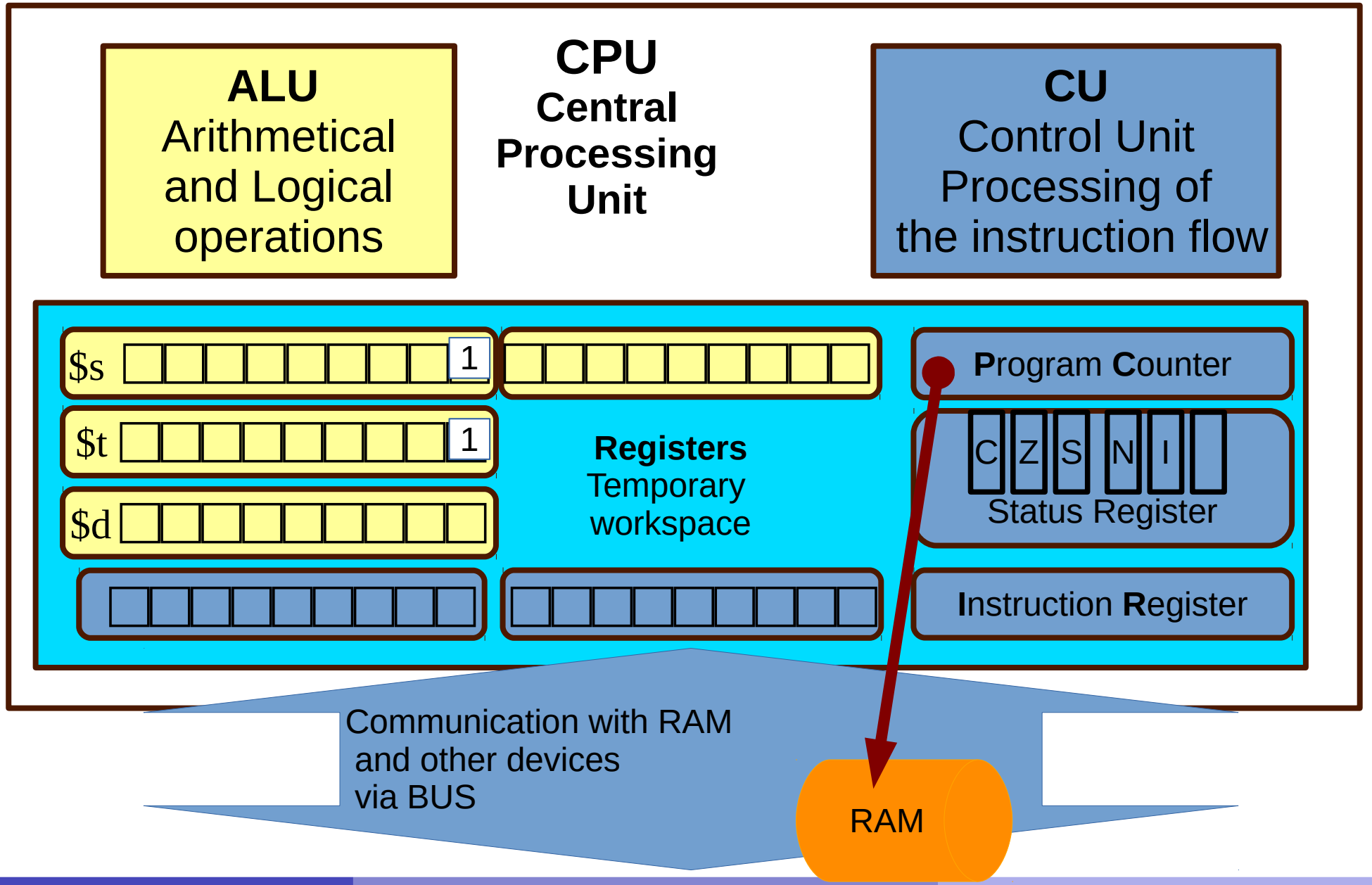
$loc	Memory location

CPU components



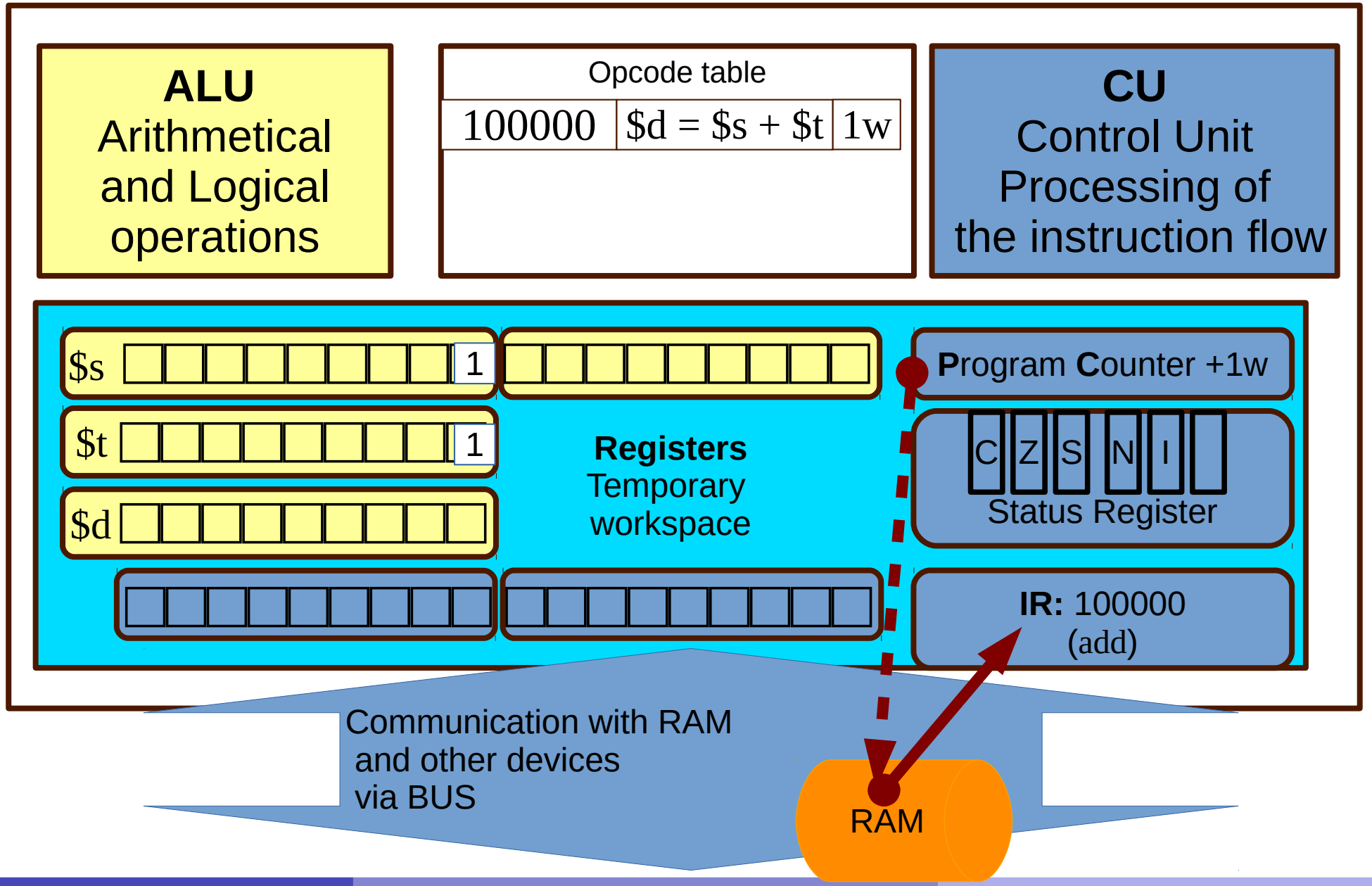
Inside a CPU


ALU
Arithmetical and Logical operations
CPU
Central Processing Unit
CU
Control Unit Processing of the instruction flow
$s
1
$t
1
$d
Registers
Temporary workspace
Program Counter
C Z S N I
Status Register
Instruction Register
Communication with RAM and other devices via BUS
RAM

Inside a CPU

- The picture represent a snapshot in time of the content of fictitious CPU registers.
- This CPU contains two values previously loaded inside the $s and $t arithmetical registers, and another value in the $loc register representing some memory location.
- At the clock stroke, the CU will load the binary values from the RAM location contained inside **Program Counter** to the **Instruction Register**.
- Since it is pointed by the program counter, the content of the memory is interpreted as an **opcode**.

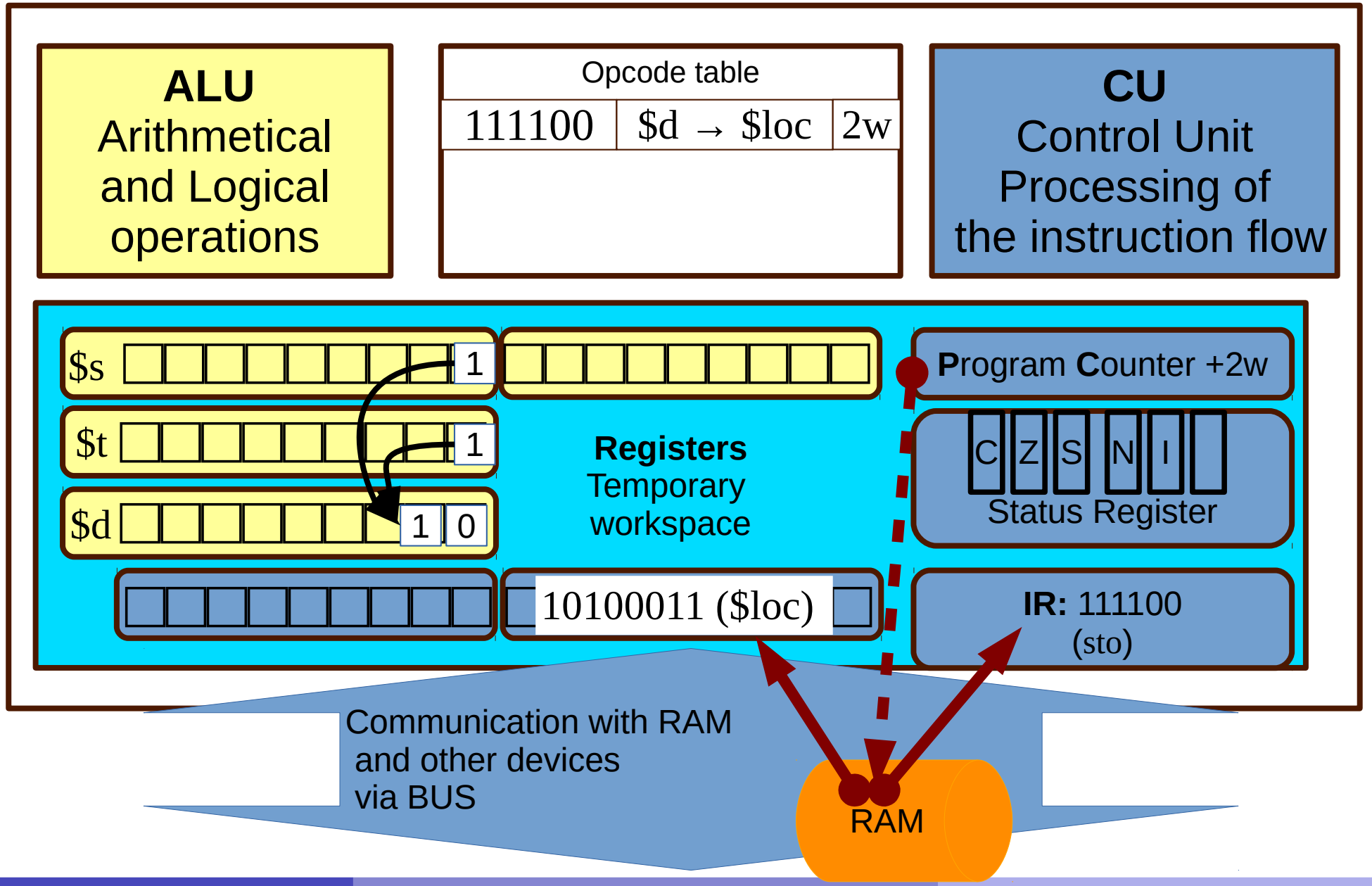
Inside a CPU – load instruction



Inside a CPU – load instruction

- The CPU looks into its microcode to find a match with the opcode. The opcode is found to be the operation `add` of summing of the content of two registers. It is a `lw` operation, so the program counter will be moved just of one location.
- At the next clock cycle, the operation will be performed by the ALU and at the same time a new instruction pointed by the Program Counter will be fetched by the CU.

Inside a CPU - executing



Inside a CPU - executing

- At the same clock stroke:
  - The arithmetical instruction will be executed by the ALU, filling the values in the $d register
  - The next operation sto is loaded in the Instruction Register by the CU. It is a 2w operation according to the microcode, where the next word in RAM is being also loaded in the $loc register at the same time.
  - At the next clock stroke:
    - the value contained in $d will be moved to the memory location pointed by the content of the $loc register, 10100011
    - The next instruction at IR+2w will be fetched

Building code

Flow chart like notation

Input data
file (ascii or binary), folder, database, picture...

Output data
file (ascii or binary), folder, database, picture...

Document
human readable
i.e. text file, code...

Binary file
NOT human readable
i.e. executable

Process
something running/executed in a computer

From code to machine language

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

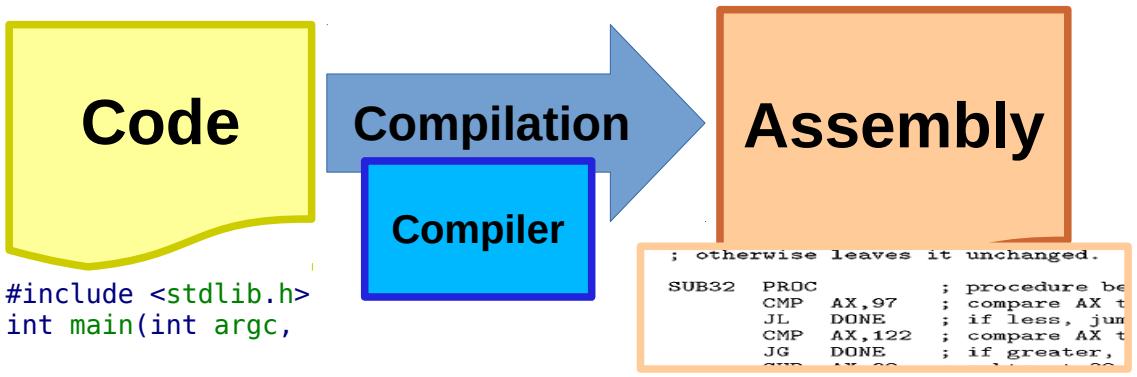
- To be executed by a computer, a program must be written in **machine language**.
- Machine language is **binary code**:

```
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**?

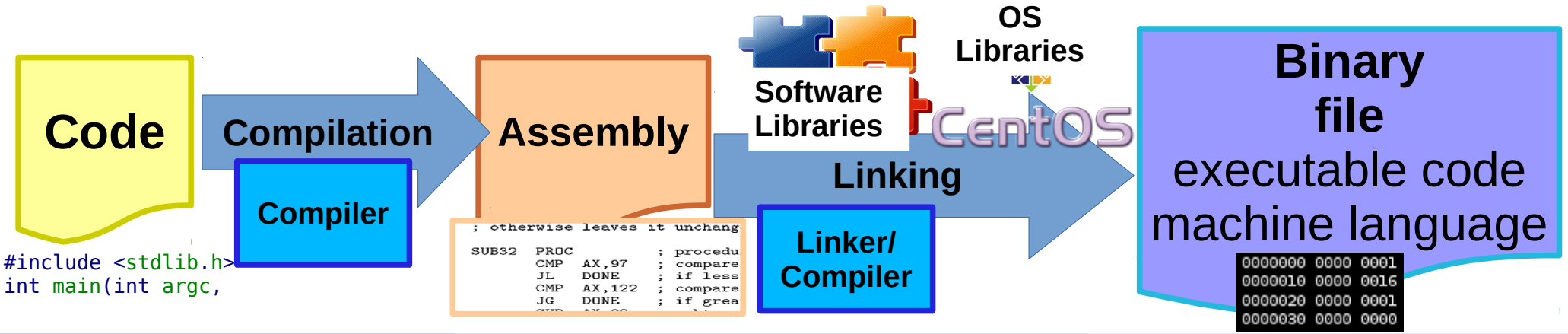
From code to machine language

- 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.



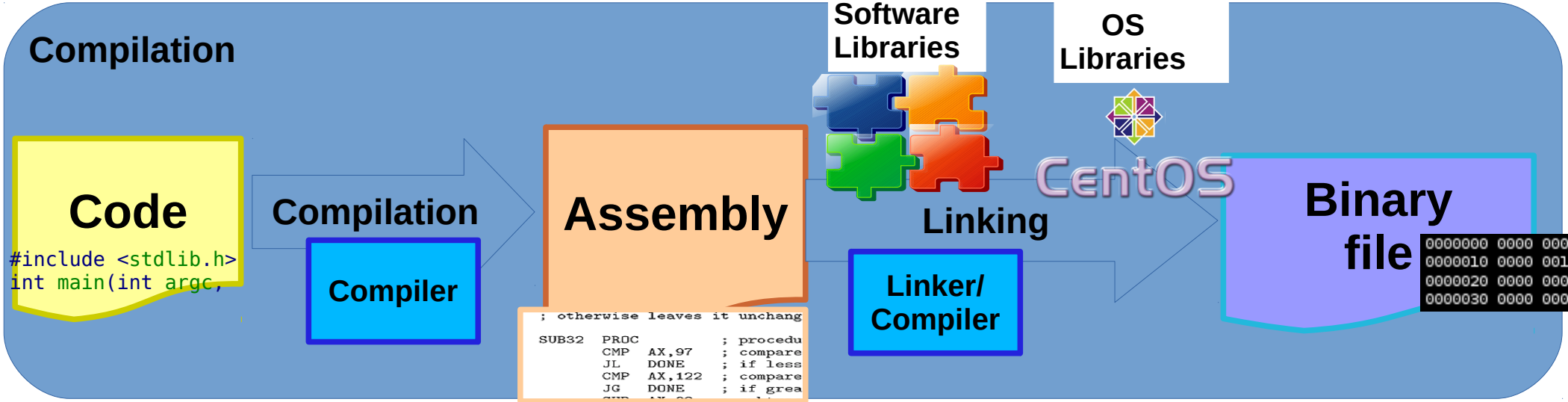
From code to machine language

- 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.



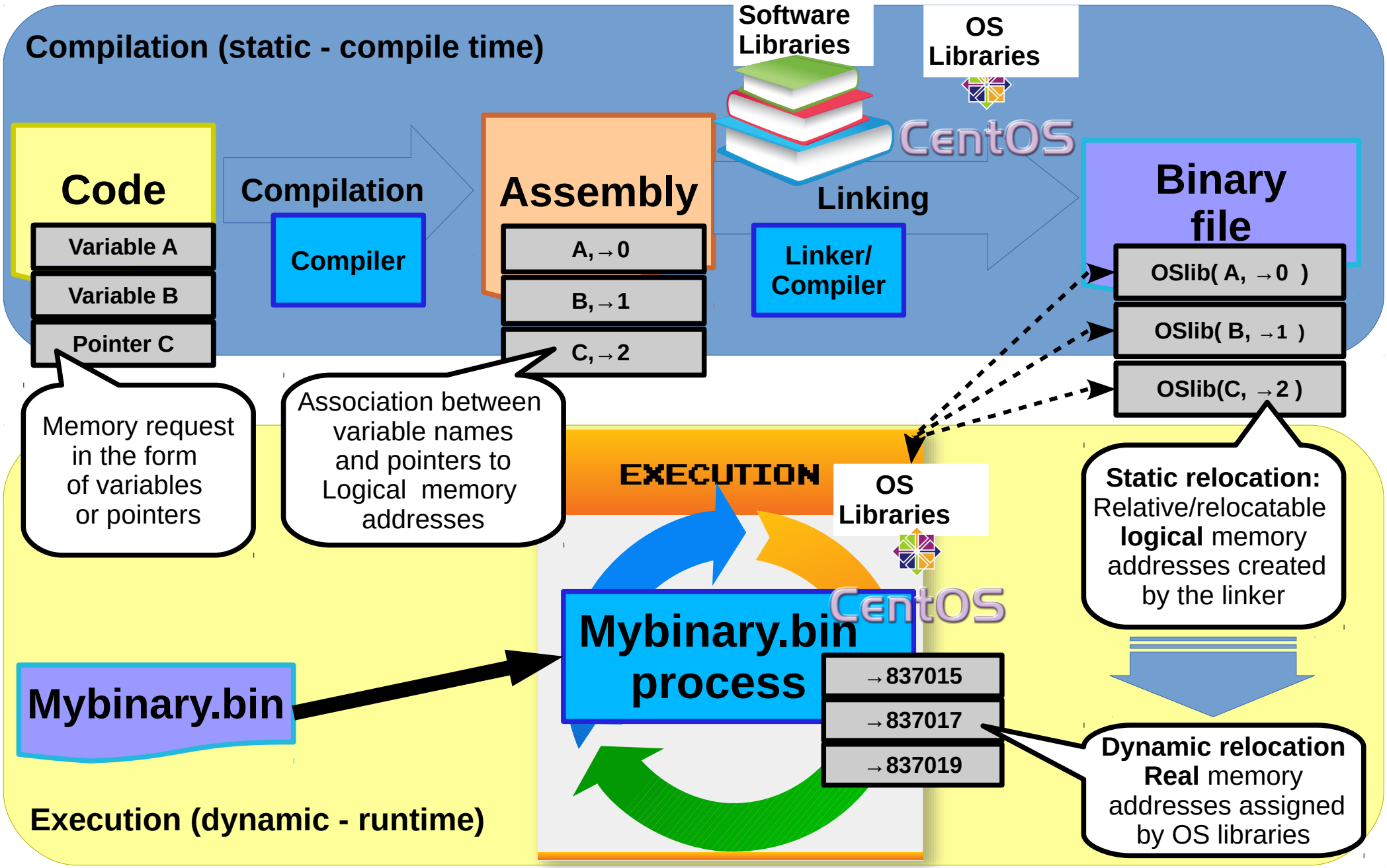
Steps to compilation
As an input-output process

- Scientist write their 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 of the compilation process, the result of the compilation process is hence a **binary file**.

Execution: from program to process

- **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 (commonly said **run**)
  - 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).
- An executed program is said to be **running** and it takes the name of **process**
  - In most operating systems every process gets a unique Process IDentifier, the **PID**, a number that identifies the program while running.
- When the code is being compiled, all the decisions taken by the compiler are said to be at "**compile time**"
- When a process is running, all the actions taken by the process and the operating system are said to be at "**runtime**"

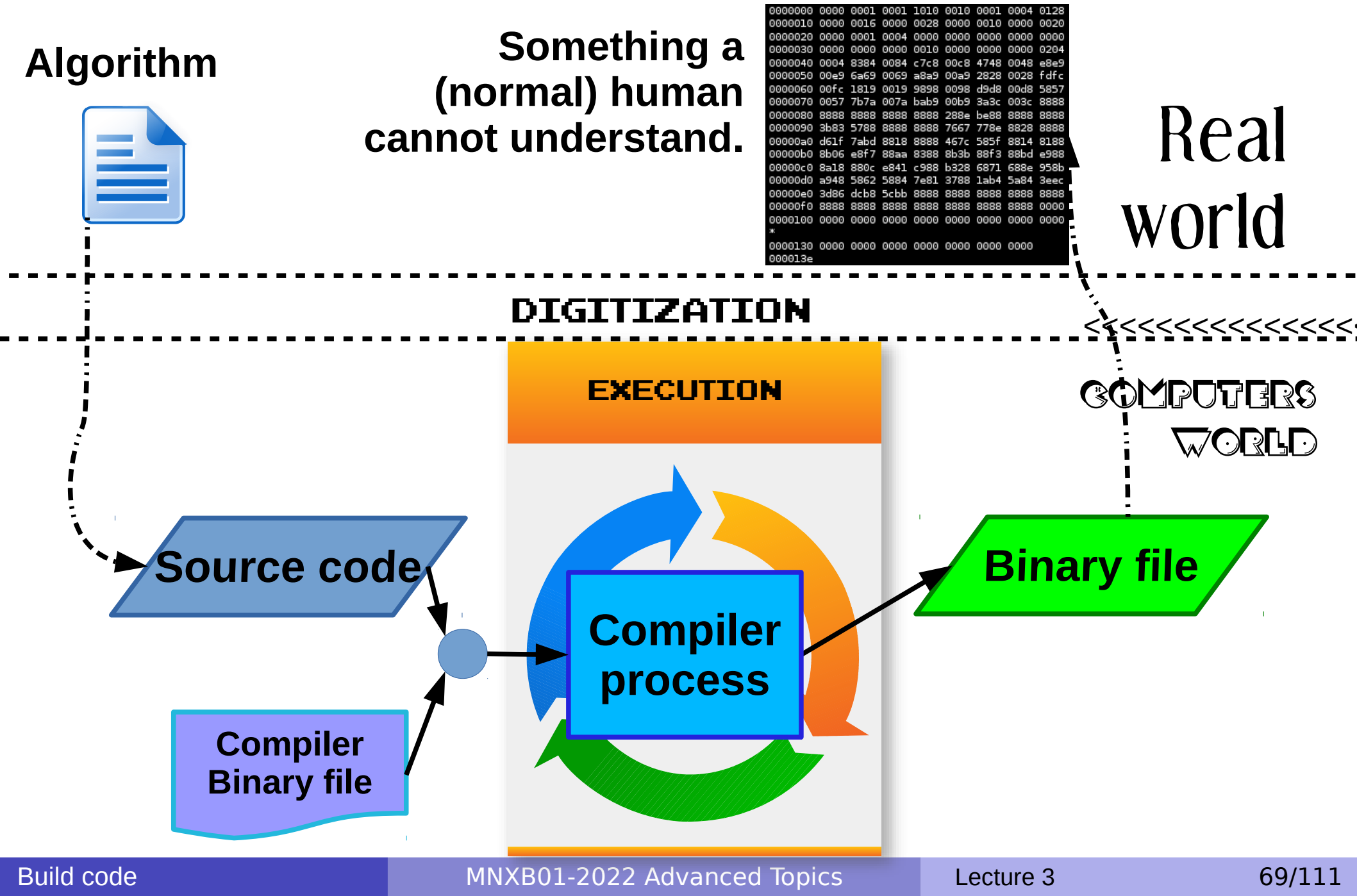
Memory Relocation



Memory Relocation

- 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/Ze just wants some memory!**
  - At **compile time**:
    - The developer memory space starts from a *virtual* location 0, that is actually mapped to some *physical* location
    - The linker **statically assigns virtual memory addresses** relative to some feature that the operating system offers to the compilation process.
      - *It's a bit like booking the tickets for a low-cost flight. You don't know where you will seat, but there will be a place for you – hopefully the flight is NOT overbooked!*
  - At **runtime**:
    - The Operating System will **dynamically relocate memory addresses** for the program to execute.
      - *Once at the airpoirt, a staff member will tell you what your seats are. But if there was overbooking you will need to wait for another flight!*

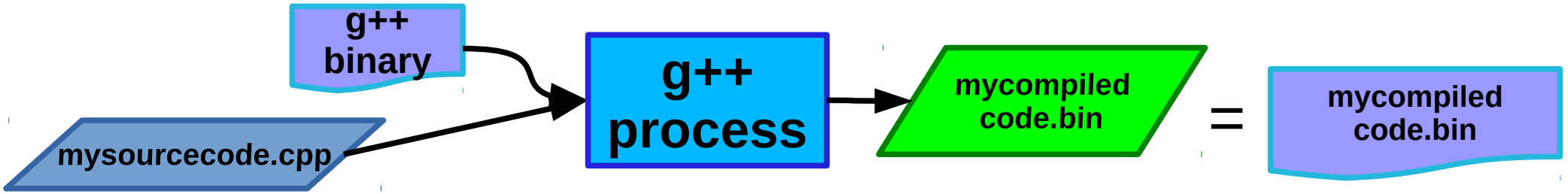
Compilation workflow



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

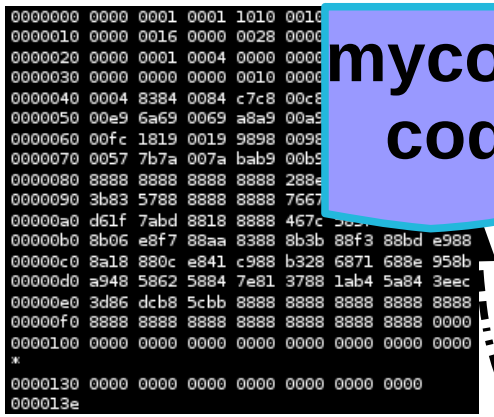
  1) **Compile** her *source code*
  Example: compile a C++ source file "`mysourcecode.cpp`" (a text file) and generate a binary file `mycompiledcode.bin`:
  `g++` `-o mycompiledcode.bin mysourcecode.cpp`
  - **run** or **execute** the binary code to see his program in action.
  Example: run `mycompiledcode.bin`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



Compilation workflow: C++

Algorithm

Mycompiledcode.bin binary is not easy to read for humans.



mycompiled code.bin

Real world

DIGITIZATION

EXECUTION

COMPUTERS WORLD

Mysourcecode.cpp

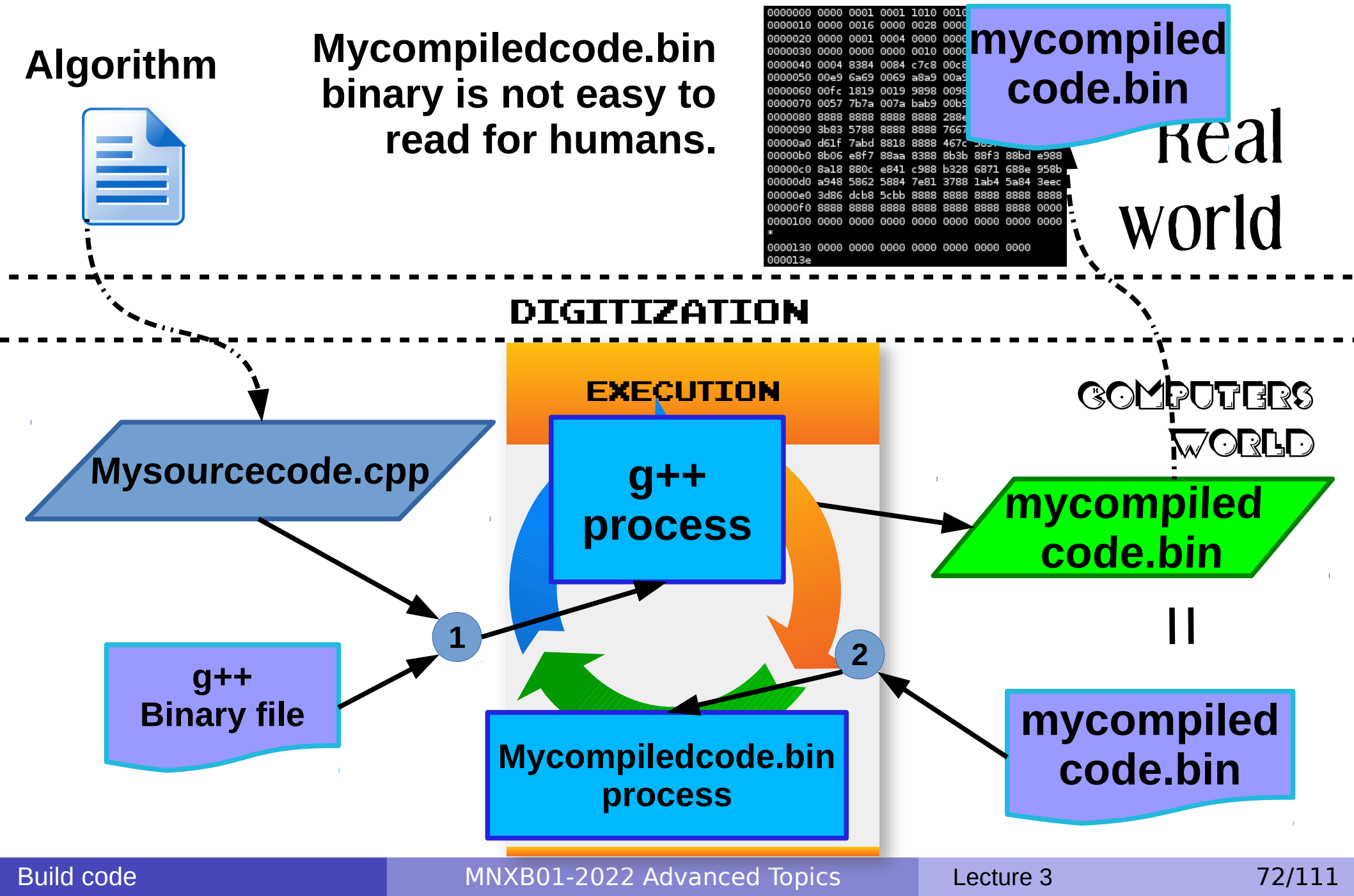
1

g++ binary

g++ process

mycompiled code.bin

Compilation workflow: C++



C++ example

Reading and printing a file to screen

```
/*
 * readgames.cpp
 *
 * Copyleft 2016 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 nintendowiigames.xml file as a file stream
      myfile.open ("../../data/nintendowiigames.xml");
    // 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

1. Compile:

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

2. Execute:

```
pflorido@tjatte:~> ./readgames.cpp.bin
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

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, but it's either done **on the fly** or uses **precompiled** binaries.
- Example: Write "Hello World" in Python:
  - 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`

Steps to interpretation: Python

Algorithm

print “Hello World”

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

Real world

DIGITIZATION

COMPUTERS WORLD

EXECUTION

print “Hello World”

1

Python interpreter binary

On the fly compilation process

Hello World! process

Python example

Reading and printing a file to screen

```
#!/usr/bin/env python
# -*- coding: utf-8 -*-
#
#  readgames.py
#
#  Copyleft 2016 Florido Paganelli <florido.paganelli@hep.lu.se>
#
#
#

def main():
    # open the file as f
    with open('../../data/nintendowiigames.xml','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

1. Pass the file to the interpreter to be executed:

```
pflorido@tjatte:~> python readgames.py
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

1. Alternatively, since we specified the interpreter at the beginning of the script, make the file executable and execute the file:

```
pflorido@tjatte:~> chmod +x readgames.py
pflorido@tjatte:~> ./readgames.py
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

A comparison of Programming languages

Compiled VS Interpreted

	Compiled	Interpreted
Performance	High	Low
Coding Complexity	High	Low
Portability	Low	High
Learning Curve	High	Low
Performance Tuning	Very High	Very Low
HW/SW requirements	Very Low	Very High
Debugging features	Medium (depends on platform/compiler)	High

Compiled, use if:

- Need performance on intensive calculations
- Require specific technologies
- Small devices with limited memory or CPU

Interpreted, 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

Compiled vs Interpreted in scientific computation

- **Interpreted** languages are used for **tedious tasks** that are not going to be executed too frequently, and **quick development**:
  - Creation of quick proof-of-concept prototypes
  - Submission of multiple computing jobs with multiple parameters
  - Streamlining/orchestration of complex computing tasks carried on with compiled languages binary code
  - Scripts that cannot be easily written in BASH.

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**
- Get the examples in the next slides at one of:
  - on the Aurora cluster : `/projects/hep/fs10/mnxb01/lecture3/lecture3_codeexamples.tar.gz`
  - Canvas – `lecture3_codeexamples.tar.gz` compressed file, expand with command:
    ```
    tar zxvf lecture3_codeexamples.tar.gz
    ```
  - My github (from last year, it's the same content): https://github.com/floridop/MNXB01-2020/tree/master/floridopag/lecture2/lecture2examples
  - MNXB01 webpage

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 readgames.sh
#

DATAFOLDER='../../data'
FILECONTENTS=$(cat ${DATAFOLDER}/nintendowiigames.xml)
echo "$FILECONTENTS"
```

1 Make the script executable and execute it:

```
pflorido@tjatte:~> chmod +x ./readgames.sh
pflorido@tjatte:~> ./readgames.sh
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
```

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

```c
/*
 * readgames.c
 *
 * Copyleft 2016 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 nintendowiigames.xml for reading
    FILE * input_file = fopen("../../data/nintendowiigames.xml", "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

1. Compile:

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

2. Execute (the object file is already executable!):

```
pflorido@tjatte:~> ./readgames.c.bin
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

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
- Numeric Precision
- 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

```
/*
 * readgames.cpp
 *
 * Copyleft 2016 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 nintendowiigames.xml file as a file stream
      myfile.open ("../../data/nintendowiigames.xml");
    // 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

1. Compile:

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

2. Execute:

```
pflorido@tjatte:~> ./readgames.cpp.bin
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

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

```
#!/usr/bin/env python
# -*- coding: utf-8 -*-
#
#  readgames.py
#
#  Copyleft 2016 Florido Paganelli <florido.paganelli@hep.lu.se>
#
#
#

def main():
    # open the file as f
    with open('../../data/nintendowiigames.xml','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

1 Pass the file to the intepreter to be executed:

```
pflorido@tjatte:~> python readgames.py
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

1 Alternatively, since we specified the intepreter at the beginning of the script, make the file executable and execute the file:

```
pflorido@tjatte:~> chmod +x readgames.py
pflorido@tjatte:~> ./readgames.py
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

Golden rules of a scientific programmer

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

- Remember the digitization 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

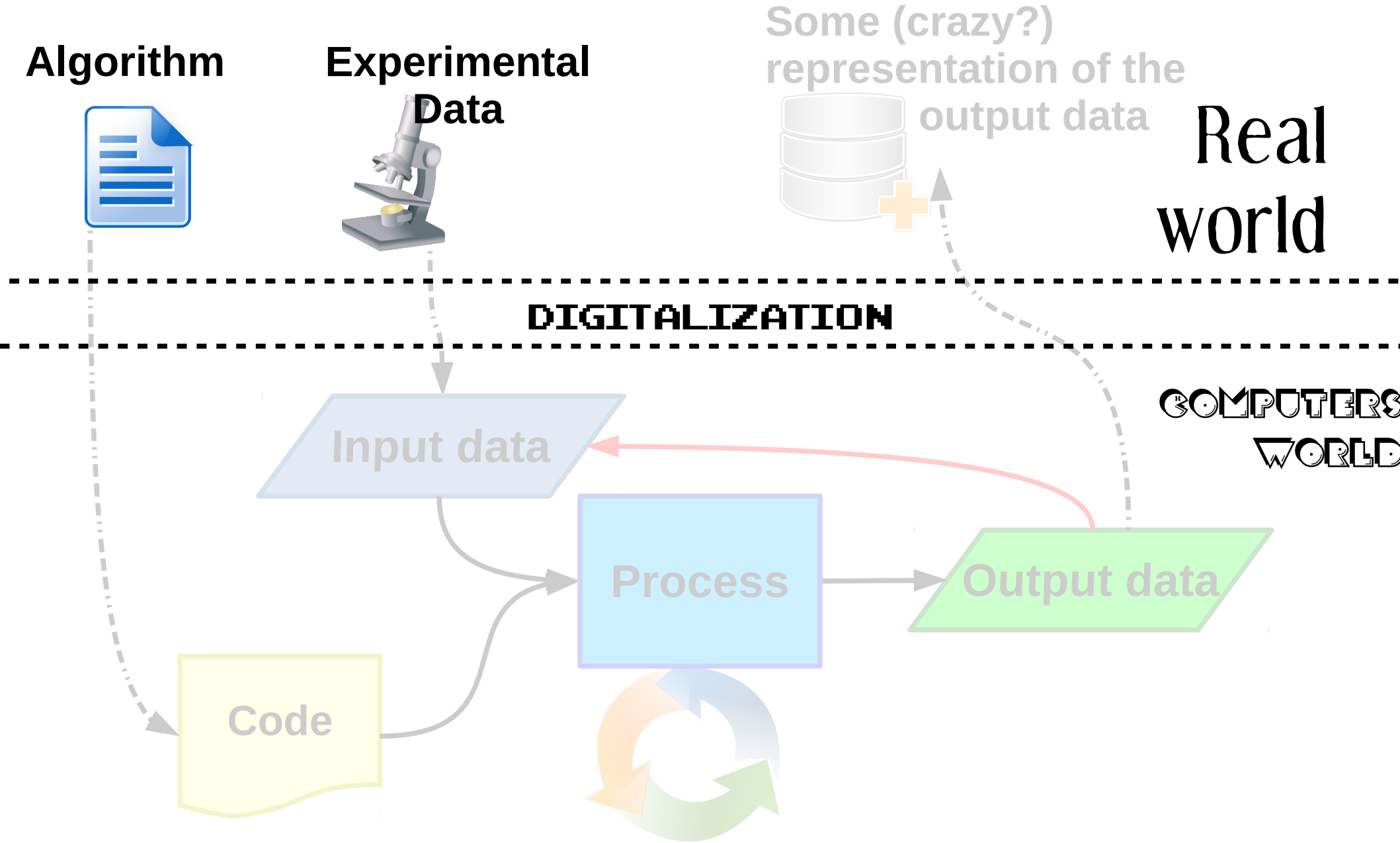
(3) Write many (significant) **comments**

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

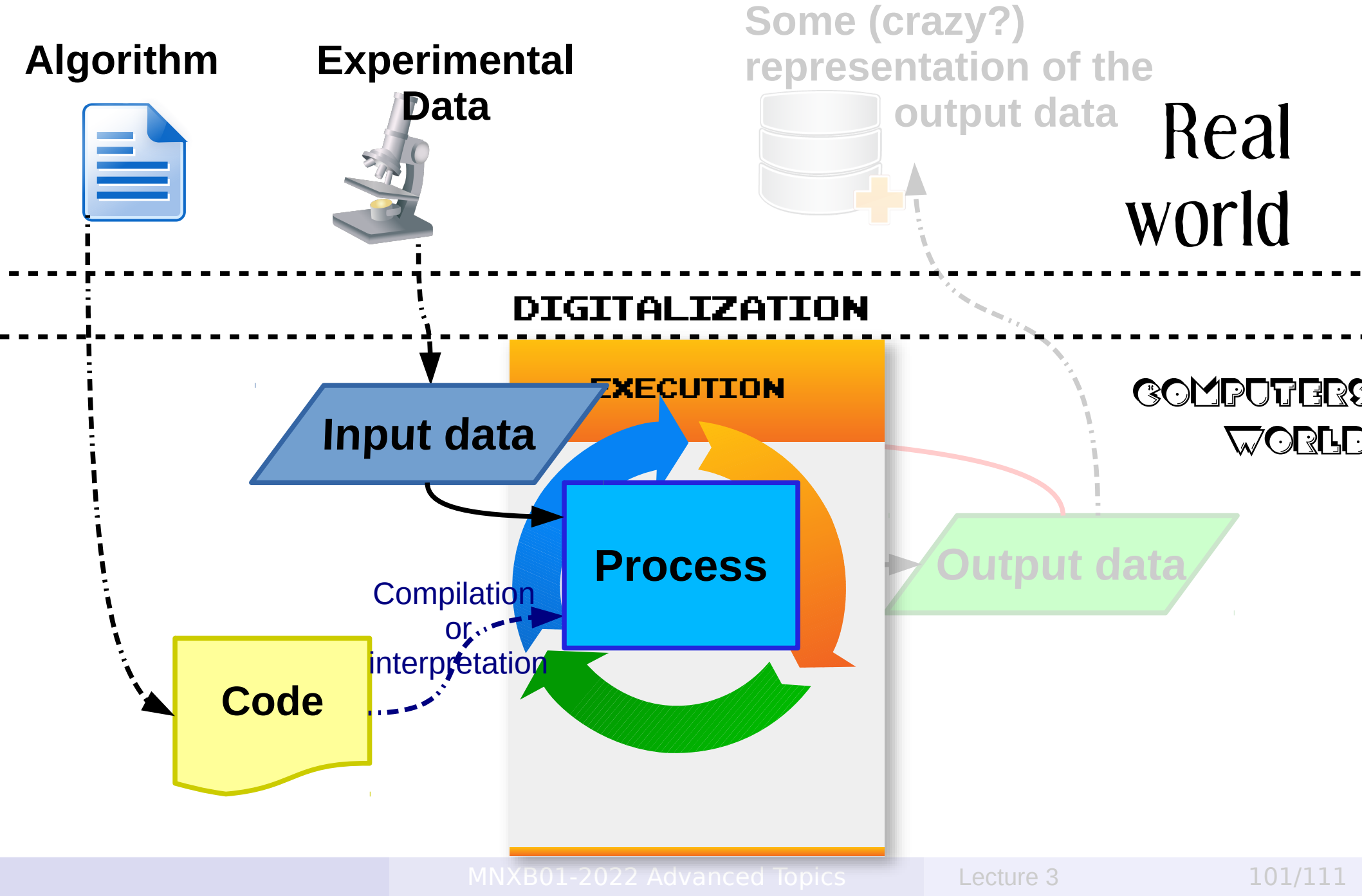
(4) Don't blame the sysadmin unless you're absolutely sure it's their fault! ;-)

Additional Material

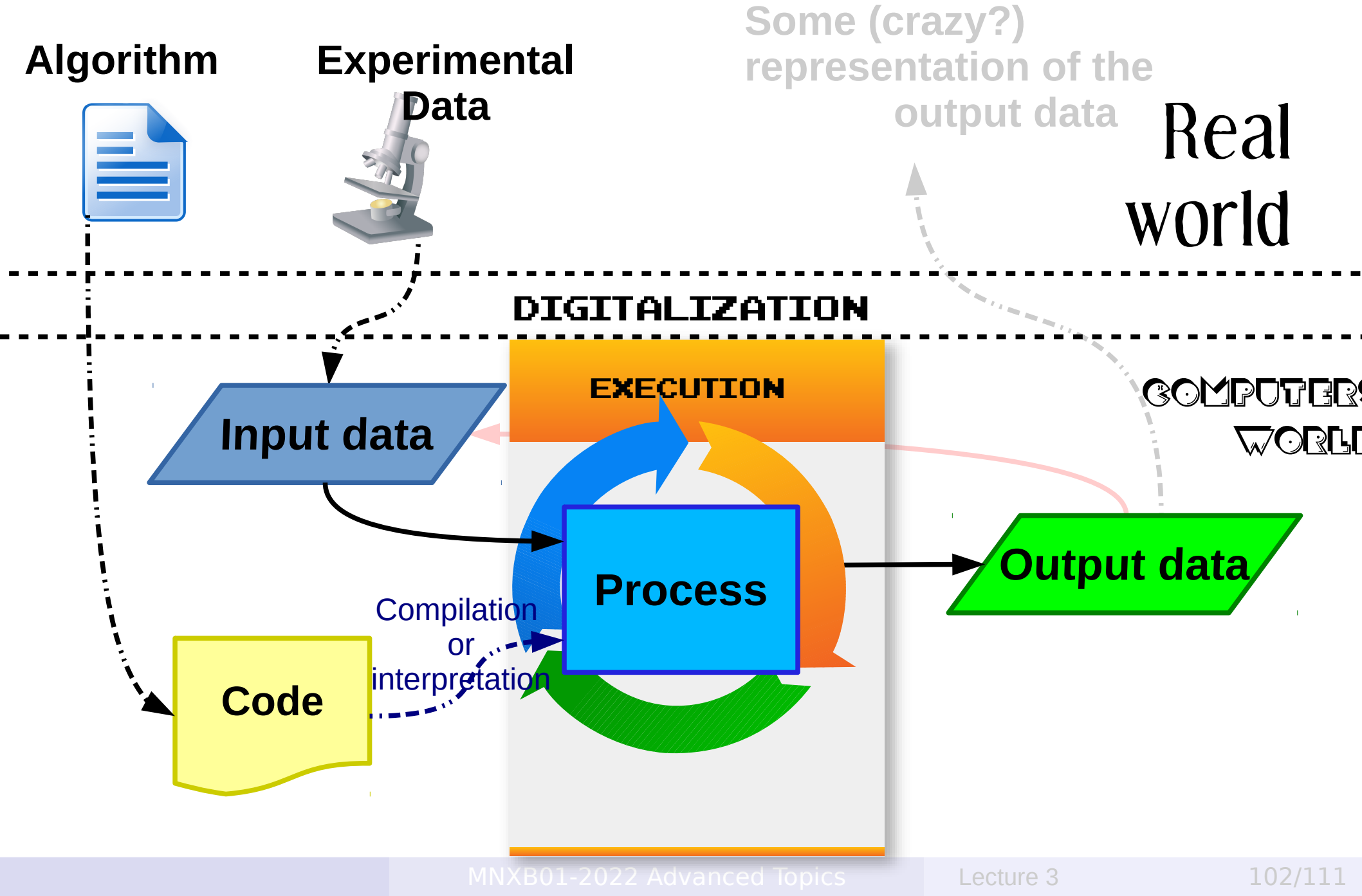
The information flow



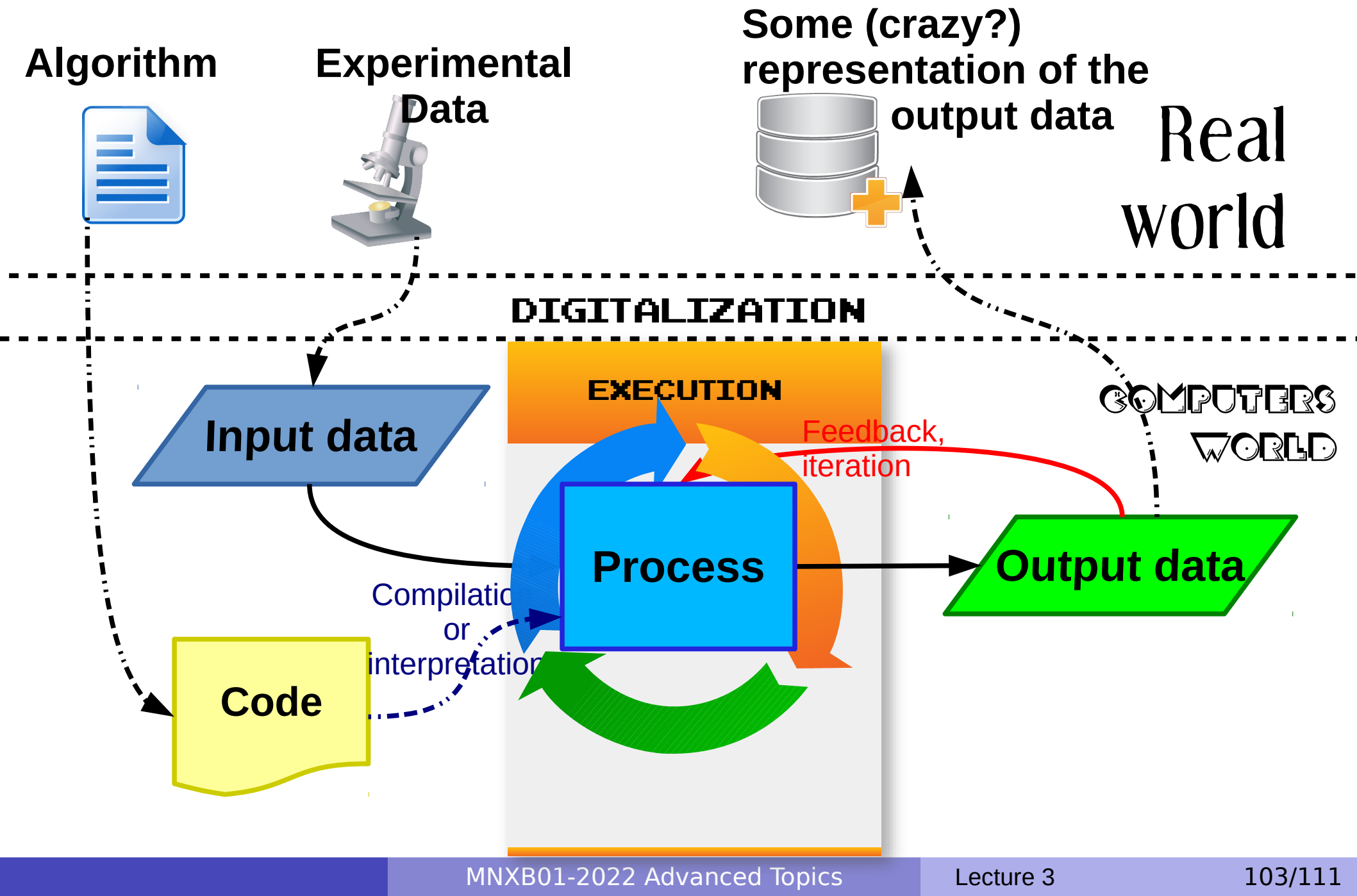
The information flow



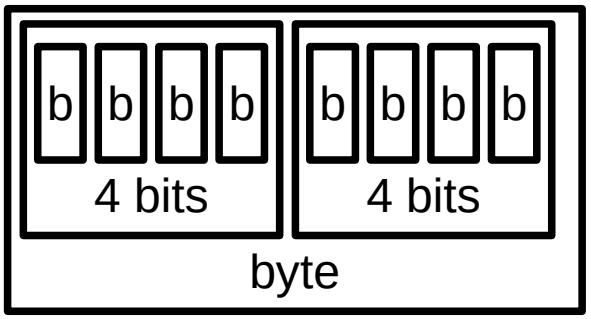
The information flow



The information flow



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

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

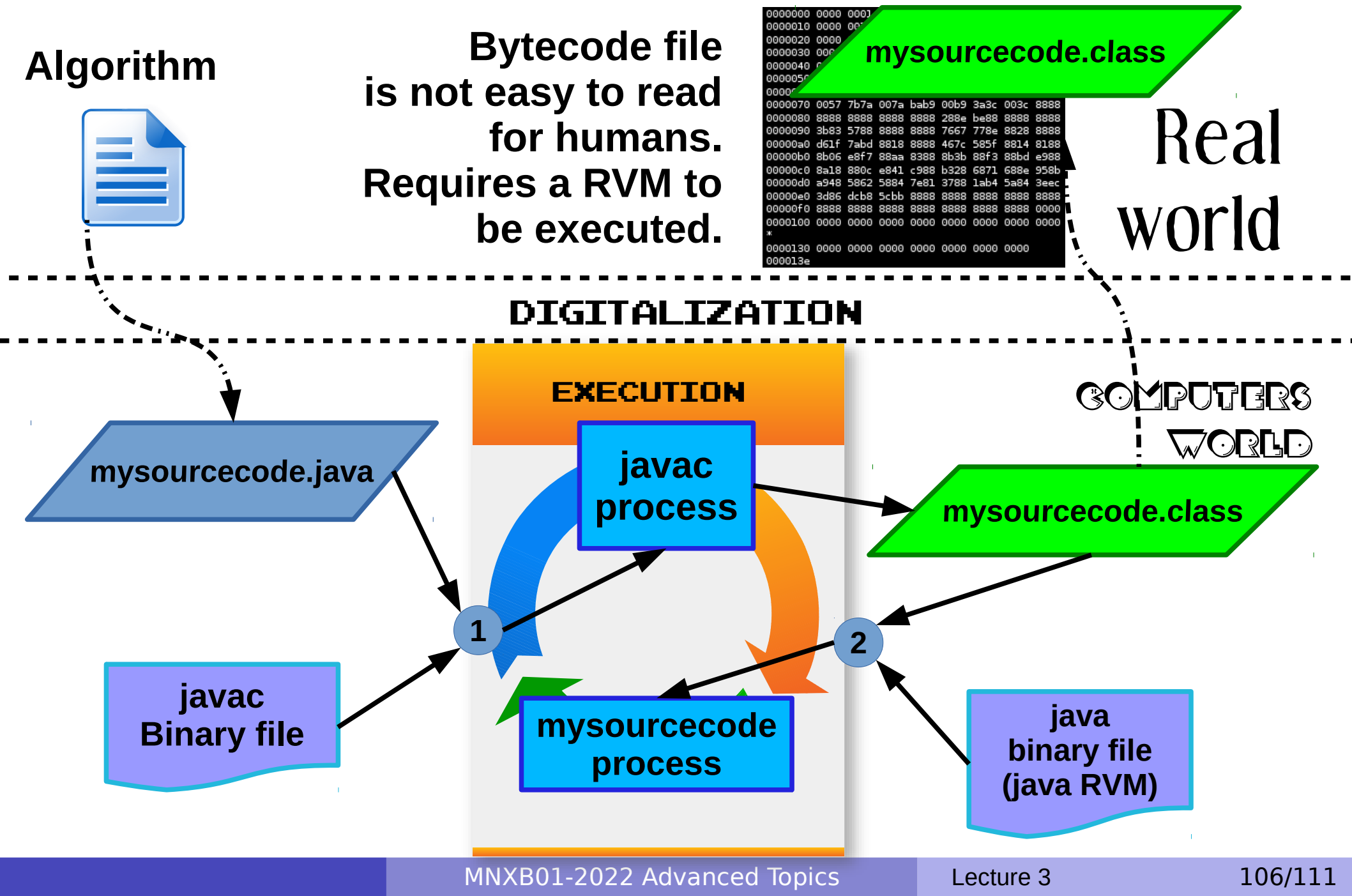
1) *Pass* the bytecode as *input file* to a *runtime virtual machine* for it to run.

   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.**

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

```
/*
 * readgames.java
 *
 * Copyleft 2016 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 readgames {
    // cause specific file errors in case of problems
     public static void main (String args[]) throws FileNotFoundException, IOException {

        String text = new Scanner( new File("../../data/nintendowiigames.xml") ).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 readgames.java
pflorido@tjatte:~> ls
readgames.class  readgames.java
```

Launch the Java Virtual Machine and execute the class file:

```
pflorido@tjatte:~> java readgames
<?xml version="1.0" encoding="UTF-8" ?>

<Data>
<Game>
<id>1558</id>
<GameTitle>Harvest Moon Animal Parade</GameTitle>
<ReleaseDate>11/10/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
<Game>
<id>32234</id>
<GameTitle>Busy Scissors</GameTitle>
<ReleaseDate>11/02/2010</ReleaseDate>
<Platform>Nintendo Wii</Platform>
</Game>
```

References

- Binary code:
  http://www3.amherst.edu/~jcook15/binarycode.html (broken link)
- 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
- Example data taken from The Game Database:
  http://www.thegamesdb.net/
  http://wiki.thegamesdb.net/index.php/API_Introduction
- Numbers representation
  https://www.ntu.edu.sg/home/ehchua/programming/java/DataRepresentation.html

Pictures references (not complete)

- http://www.jegerlehner.ch/intel/
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- http://en.wikipedia.org/wiki/X86
- http://en.wikipedia.org/wiki/Protection_ring