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Introduction to C++ (and C)

Cédric Zanni

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Operating mode

- **Ask questions**
- **Feedback requested !**
  - Speed/Difficulty/Interest (both lectures and practical works)
- **Between lectures**
  - Try to finish/advance exercices
  - CppIsoGuidelines or blog post to read
- **Come back with questions if something is not crystal clear !!!**

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First, a question…

- **Why did you choose to follow a lecture on C++ ?**

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Lecture Plan

- **Why C++ (and C) and a bit of history**
- **What type of programming language is C++ (and C)**
- **A small word on computer architecture**
- **Base syntax (C and C++)**
  - Types, variables
  - Control flow
  - Functions
  - Arrays

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C strong points

- Open normalized standard know by *¿most?* developers
- Optimization and control of memory allocation
- Limited number of concepts to understand (*¿easy?* handling)
- Relatively close to machine code (no hidden cost)
- Compile directly to machine code

zero overhead principle

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C weak points

- **No exception management**
- **No object oriented programming**
- **No special support for memory allocation** (no garbage collector, ...)
- **A lot of bugs if we are not careful**

limited abstractions !

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limited abstractions !

Comment : Reason why we will focus mostly on C++

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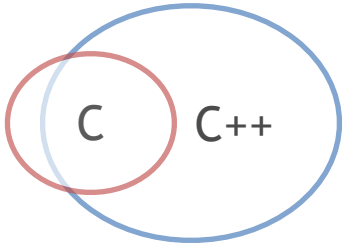
limited abstractions !



Comment : Reason why we will focus mostly on C++

Comment : C++ is **nearly** a superset of C

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C++ a well criticized language

- **Wikipedia page : Criticism of C++**
  - Large number of listed criticism concern old compilers and c++ version
- **Too hard and too complicated**
- **But …**

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Brian Kernighan : « C++ has been enormously influential. … Lots of people say C++ is too big and too complicated etc. etc. but in fact it is a very powerful language and pretty much everything that is in there is there for a really sound reason: it is not somebody doing random invention, it is actually people trying to solve real world problems. Now a lot of the programs that we take for granted today, that we just use, are C++ programs. » consideration …

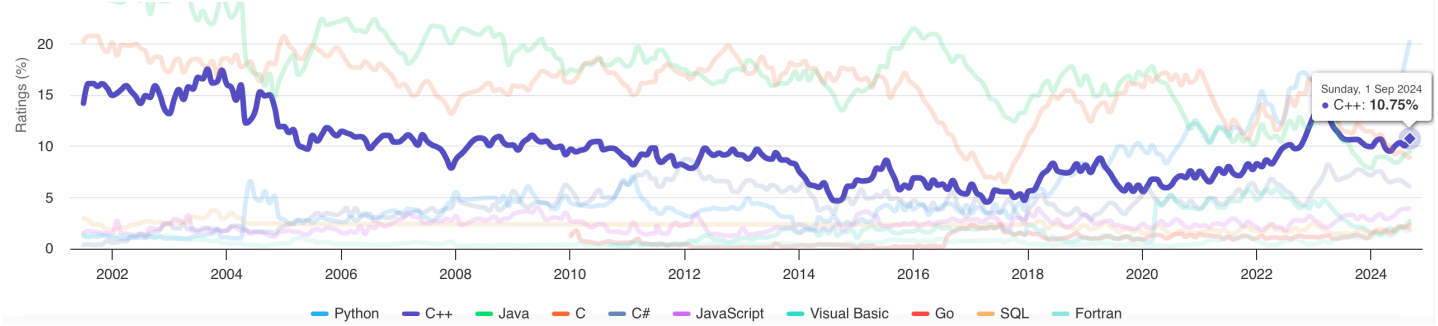
Why C++ when Rust is rising ?

- **Rust is currently safer, but you still have to use *Unsafe Rust* if**
  - you want interoperability with C
  - you need some optimization (advanced data structures, …)

- **What about Carbon** (google), **Hylo** (open-source), cppfont, circle, …

- **Large existing code base are still written in C++**
- **C++ is the main language for GPGPU programming**
- **It's interesting to see how to make a language safer (C -> C++)**
- **C++ is still evolving and moving toward safety profile**

TIOBE index



Learn both depending on your target domain/job !

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Where is C++ used ?

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Where is C++ used ?

AIRBUS SPACEX TESLA

BOEING Mercedes-Benz

NASA Embedded system

BostonDynamics

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Boston Dynamics

Alphabet

Meta

Office

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chrome Firefox

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Where is C++ used ?

Embedded system

System programming

Where is C++ used ?

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BOEING Mercedes-Benz

NASA Boston Dynamics

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Meta

Office

chrome Firefox

Microsoft

macOS

System programming

Java JVM (Java Virtual Machine)

Parallels

Virtual machine

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JPMorgan Chase & Co. Banking

Where is C++ used ?

Embedded system

Databases

System programming

Virtual machine

Banking

Where is C++ used ?

Embedded system

Maths and simulation

Databases

System programming

Virtual machine

Banking

Where is C++ used ?

Image, Geometry, Video editing, CAD, ...

Embedded system

Maths and simulation

Databases

System programming

Virtual machine

Banking

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Where is C++ used ?

Unity

UNREAL ENGINE

GODOT Game engine

Video game engine

AIRBUS SPACEX TESLA

DASSAULT SYSTEMES

OpenCV

nTop

Adobe

CGAL

BOEING

Mercedes-Benz

Image, Geometry, Video editing, CAD, …

NASA

Boston Dynamics

Embedded system

MATLAB

Ansys

Wolfram Mathematica

Maths and simulation

Alphabet

Meta

Office

MySQL

mongoDB

Databases

chrome

Firefox

Microsoft

macOS

System programming

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Virtual machine

JPMorgan Chase & Co.

Banking

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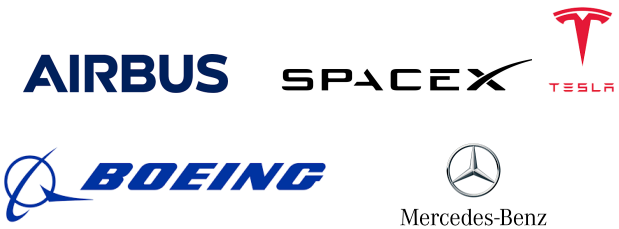
Where is C++ used ?

Video game engine



Image, Geometry, Video editing, CAD, ...

Embedded system

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GPGPU

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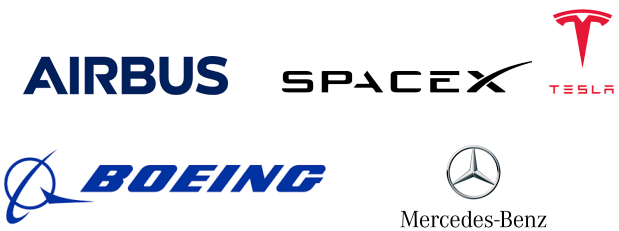
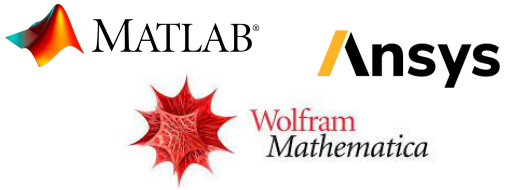


Embedded system

Image, Geometry, Video editing, CAD, ...



Maths and simulation

GPGPU

Databases

Machine learning

System programming

Virtual machine

Banking

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Examples

pybind11

C++ library (binding)

Desktop C++ app

Google Earth

TensorFlow

C++ library

Ported to web using Emscripten
(Compiled to WASM)

emscripten

emscripten

WA

WA

Google V8, JavaScript and WebAssembly engine written in C++

IceSL
modeler and slicer

Desktop C++ app

Examples : C and C++ in Python

- **CPython (Python reference implementation)**
  - is written primarily in C
- **Python standard library**
  - contains many modules implemented in C
- **NumPy, Pandas, SciPy**
  - are mostly written in C with a few C++
- **TensorFlow, PyTorch, OpenCV, VTK, PyQt…**
  - are mostly written in C++

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Comment : for performance consideration …

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Comment : for performance consideration …

Comment : … can also find python library mostly written in Rust

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Where is C used ?

- **System programming**
  - Operating system (OS) such as Linux
  - Microcontrollers: transports (planes, cars, …)
  - Digital signal processor (DSP) : remote controller
  - Embedded processors (portable electronics)
  - …

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  - ...
- **In python...**
  - Reference Python interpreter
  - Large part of python standard library
  - Possibility to extend python using C

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A bit of history

- **Evolution of C and C++ over time**
  - 1972 : invention of C by Dennis Ritchie
  - 1978 : The C Programming Language (stabilisation of the language)
  - 1979 : C with Classes (first implementation)
  - 1985 : The C++ Programming Language, 1st edition
  - 1989 : first C norm(C89) by American National Standard Institute
  - 1991 : ISO C++ Committee founded
  - 1998 : first C++ norm (minor update in 2003)
  - 1999 : C99 one of the most commonly used C norm
  - **C11, 18, *23 (underway)***
  - **C++11, 14, 17, 20, 23, *26 (underway)* -> « Modern » C++**

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Object-oriented programming and modeling

Key concept

Object-oriented programming and modeling

Key concept

- **Encapsulation**
  - hide implementation details
  - guarantee a class invariant
- **Aggregation**
  - define composite objects from several simpler objects
- **Extension / Inheritance**
  - define a class from another existing class, e.g. derive
  - class hierarchy

Object-oriented programming and modeling

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Strength : Allow local reasoning !

What type of programming language is C++ (and C)

	Type checking	Type safety	Type semantics	Execution Strategy	Memory management	Object oriented	Functional
Python	dynamic	weak	reference	Interpreted (*)	Garbage collector	YES	PARTIAL
Java	static + dynamic	strong	reference (classes) value (primitive types)	Compiled + Interpreted	Garbage collector	YES	PARTIAL
Rust	static	strong	value + explicit references	Compiled	Borrow Checker	YES	PARTIAL
C	static	weak	value (*) + explicit pointers	Compiled	Manual	NO	NO(*)
C++	static + dynamic	strong	value (*) + explicit pointers/ references	Compiled	Semi-automatic (RAII)	YES	PARTIAL

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What is "Modern C++"

- **Static type safety**
  - Well-specified interfaces
- **Resources safety**
  - Constructors/Destructors, RAII
- **Abstraction**
  - Often zero overhead
- **Encapsulation, invariants**
  - Classes
- **Generic programming**
  - Templates
- **Simplicity for most developers**
  - Complexity hidden in libraries
- **Multiparadigm programming**
  - Object oriented, functional, concurrent, ...

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Multiparadigm

- **Example :** traversing statically typed container of objects of polymorphic type

```
template<class C>
void drawAll(C& drawable_container)
{
    for_each(drawable_container.begin(), drawable_container.end(),
             [](Shape*) { p->draw(); });
}
```

Multiparadigm

- **Example :** traversing statically typed container of objects of polymorphic type

Static type used to generate optimized iteration on container

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Function passed as parameter of algorithm

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Dynamic polymorphic call (**inheritance**)

Function passed as parameter of algorithm

C(++) : A compiled language

- **From source code to execution**

Source code

```
int main () {
    int a = 0;
    int b = a+1;
    return b;
}
```

Compilation

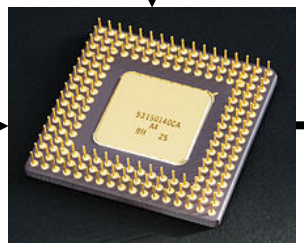
Assembly language

```
MOV EAX, EBX
ADD EBX, ECX
…
```

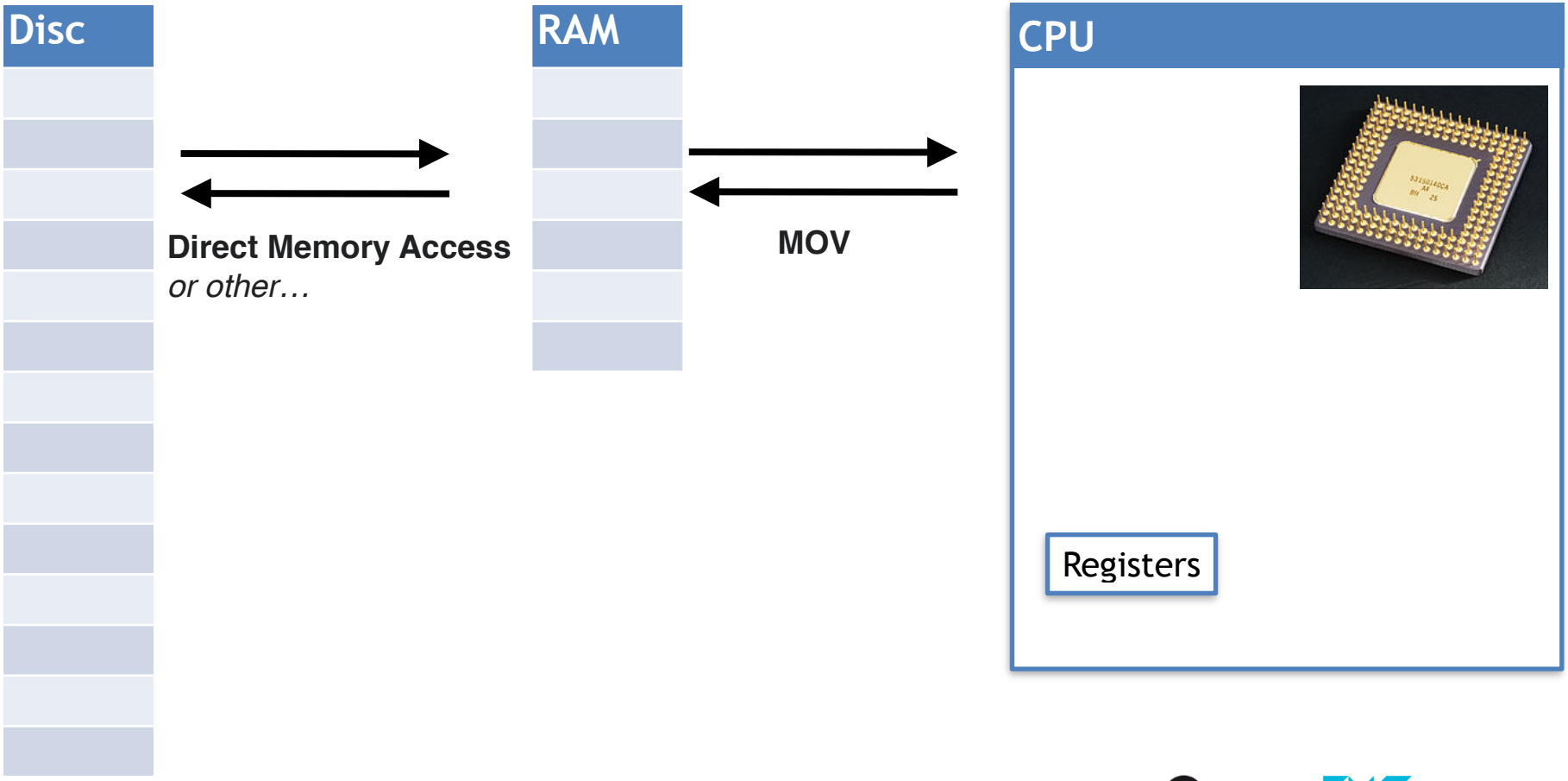
Assembly

Machine code (binary)

```
01001100110001100
11100110011001100
01110011110001110
01110000110010011
…
```

Input data →  → Output data

Architecture *(oversimplified)*



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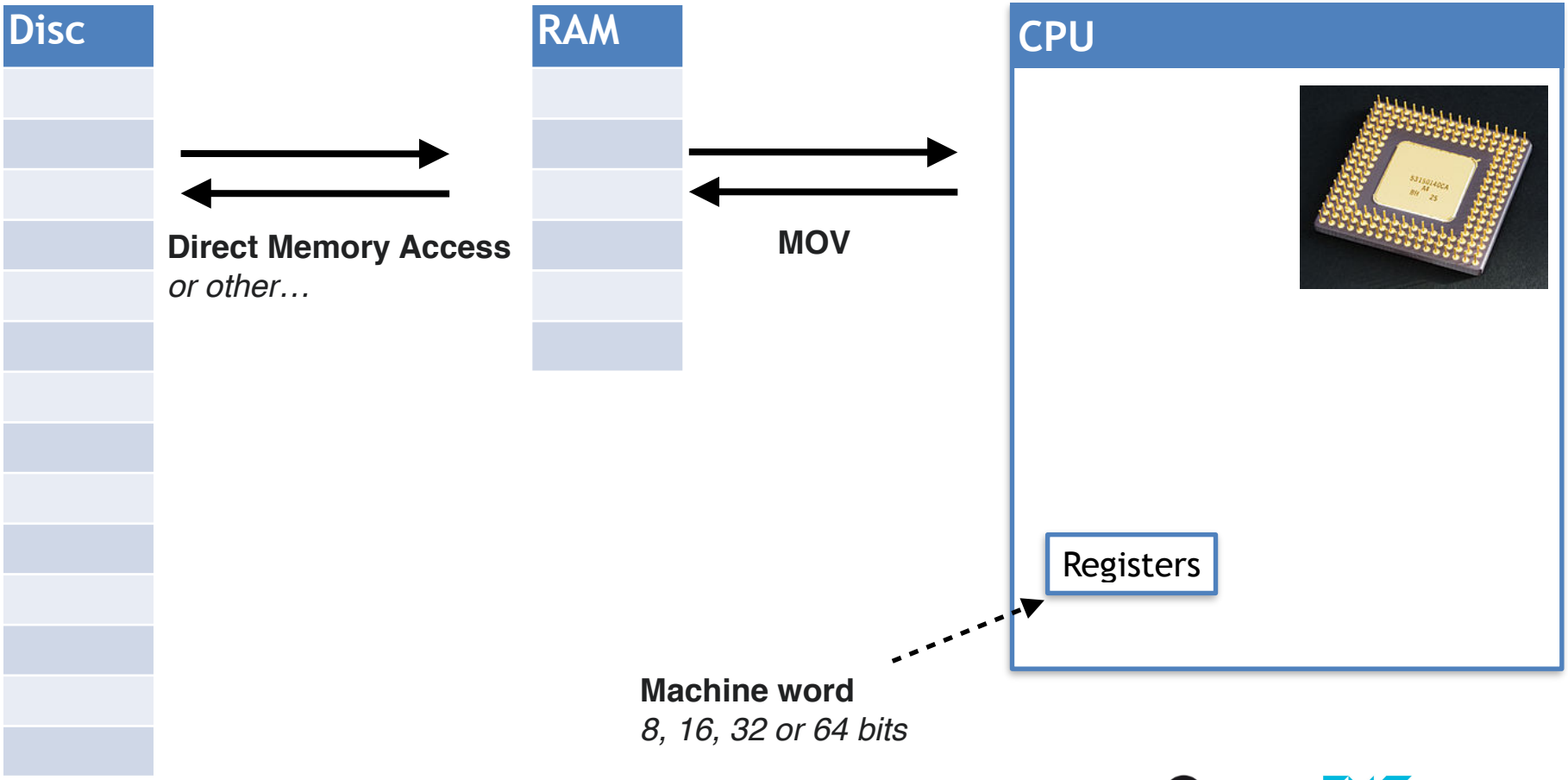

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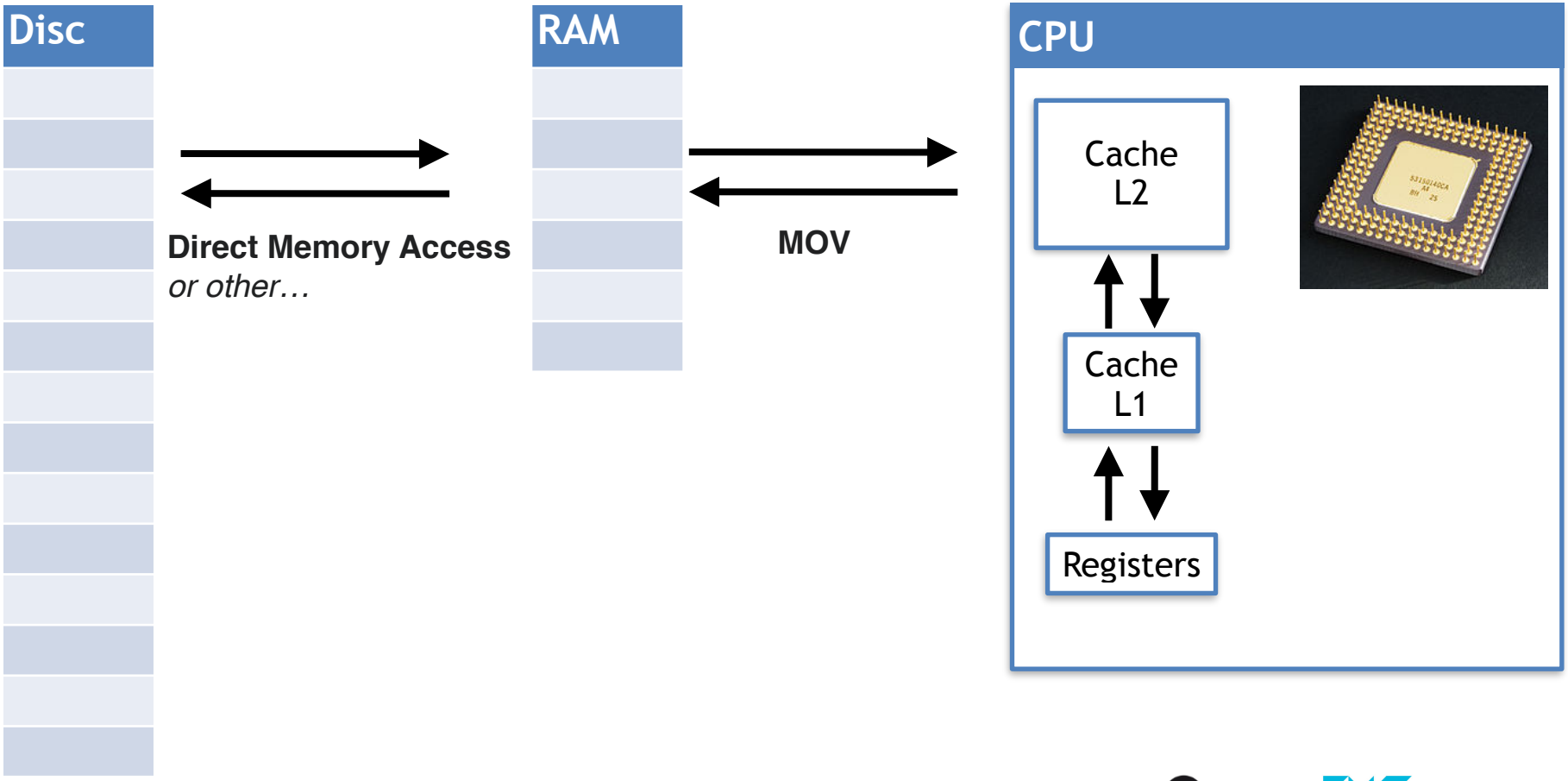

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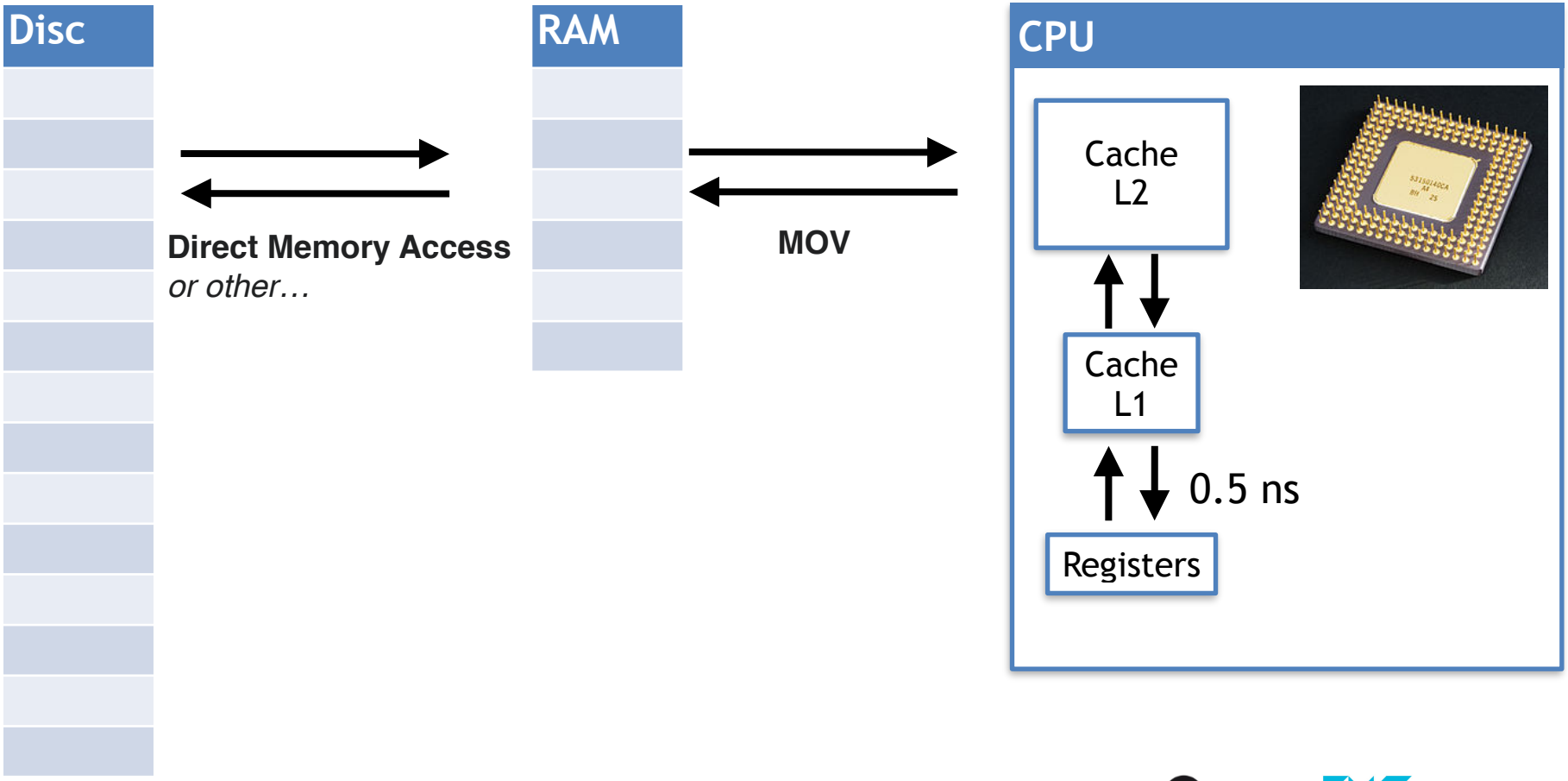

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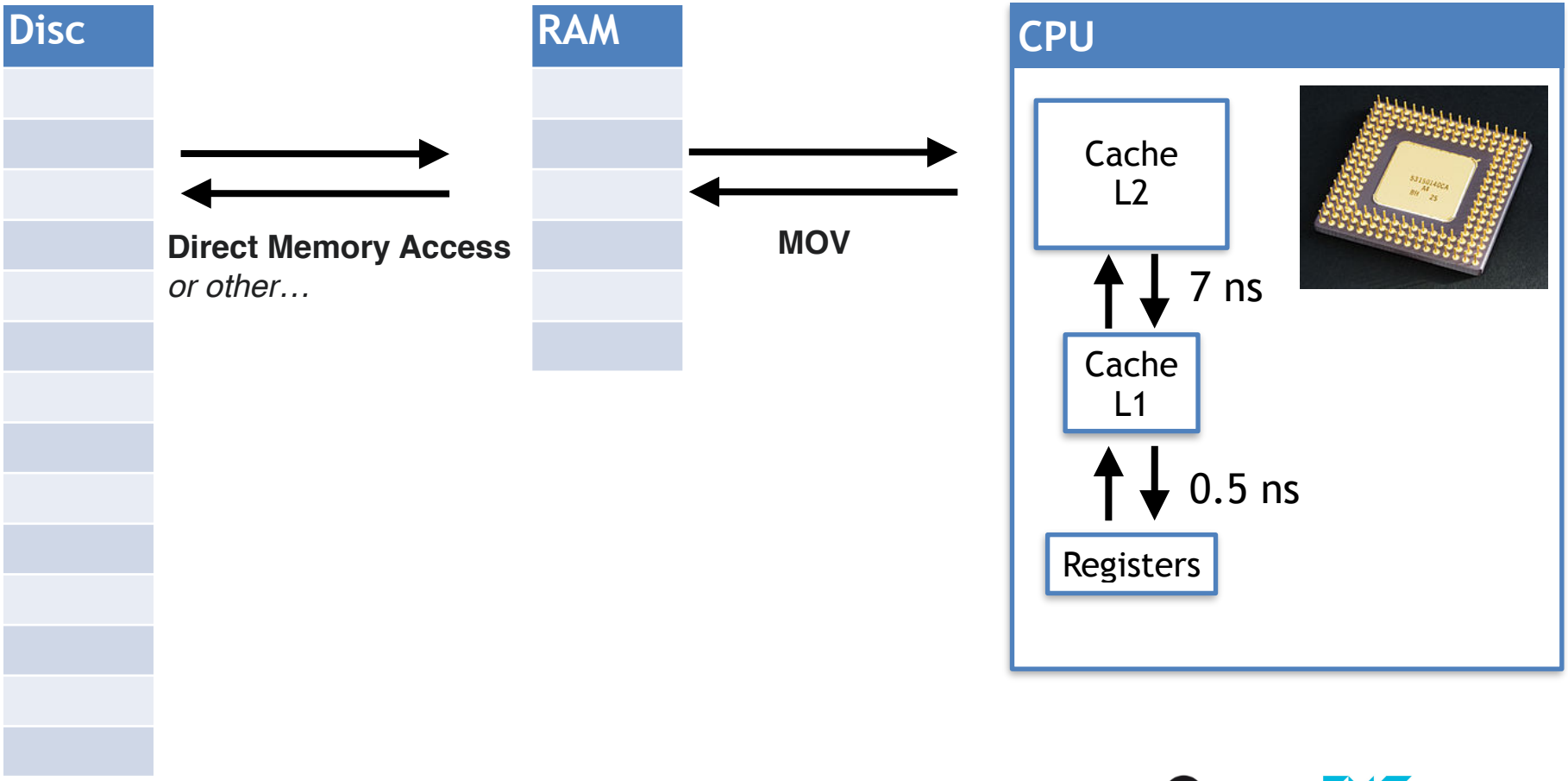

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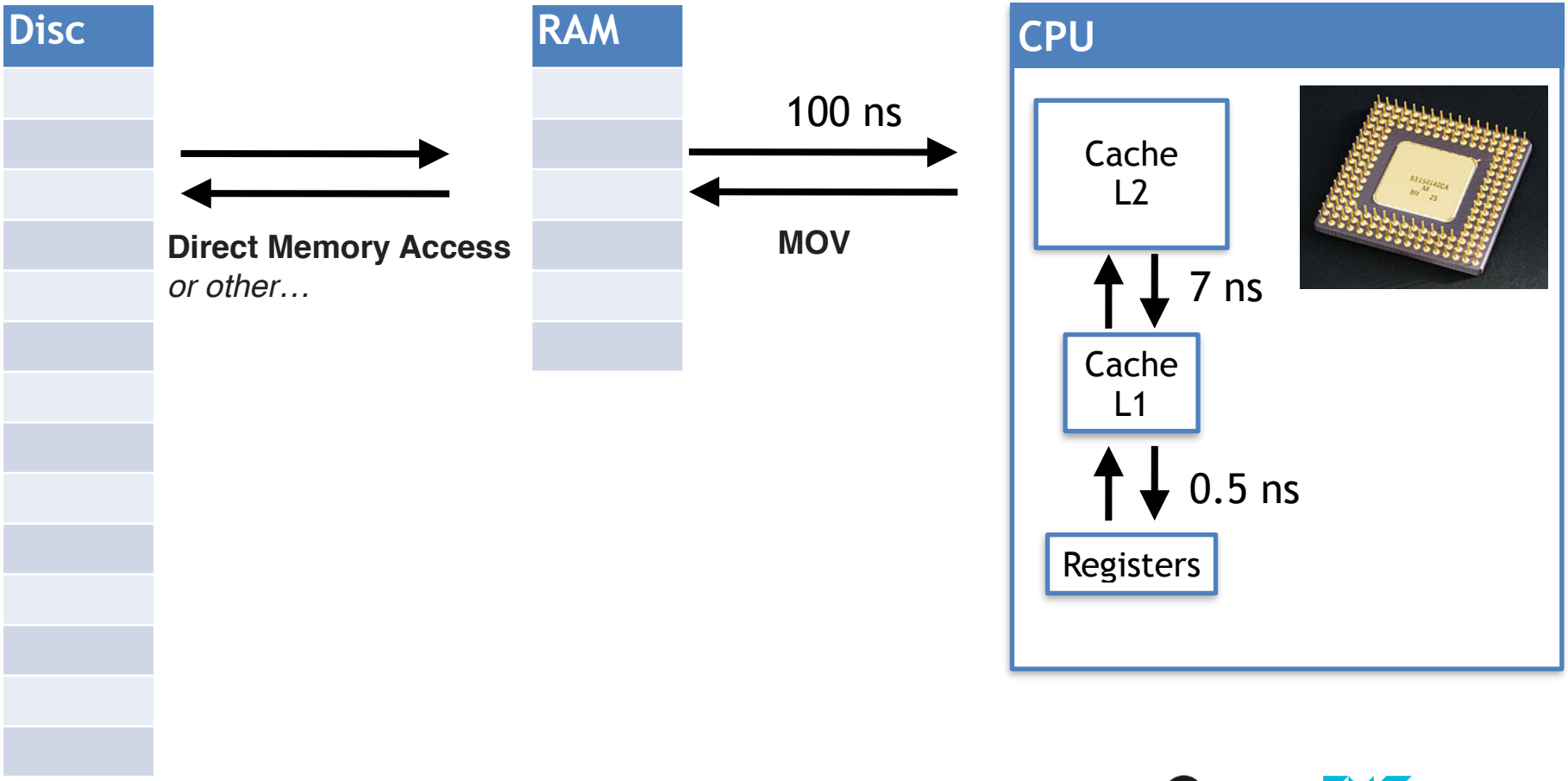

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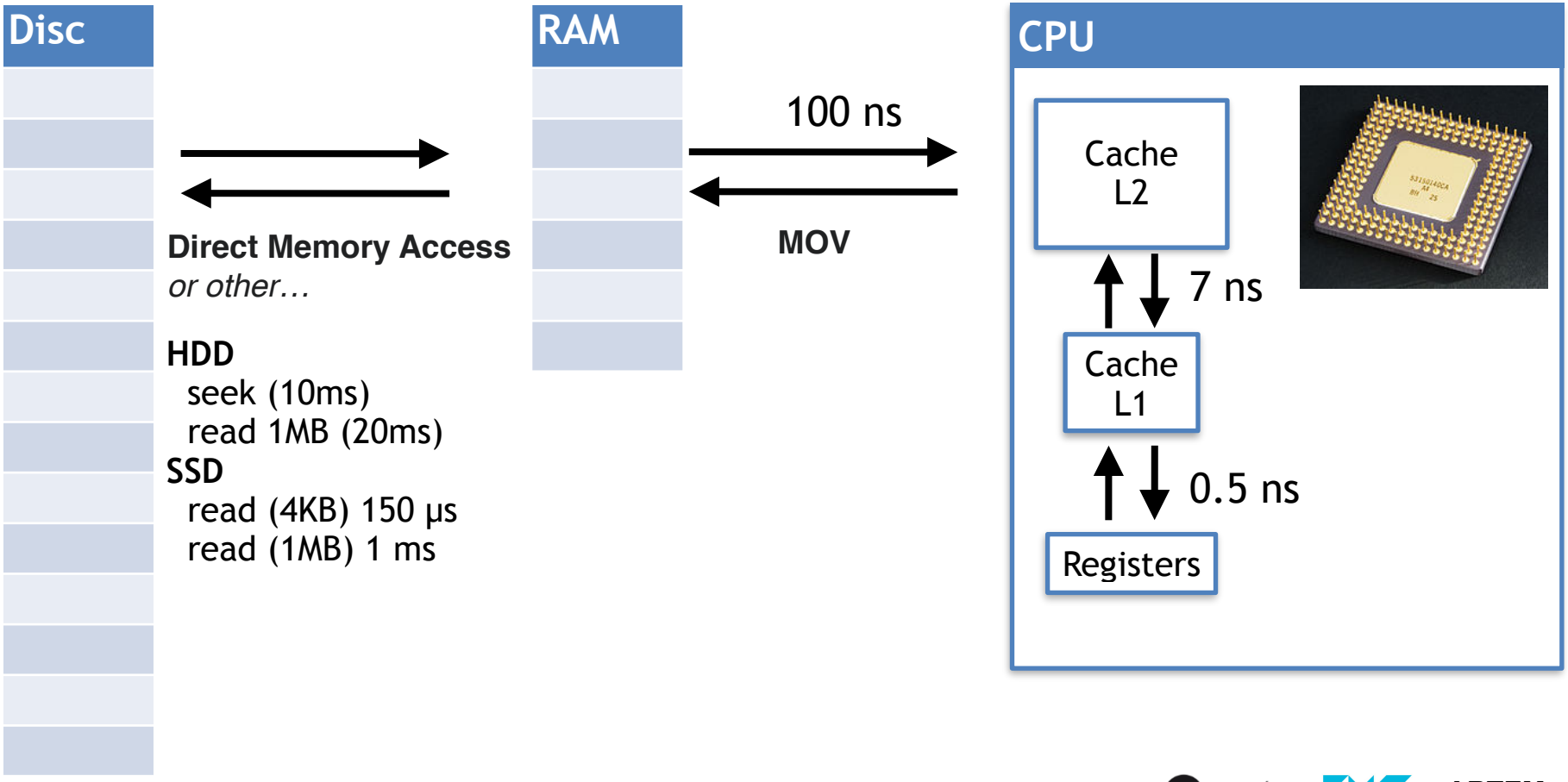

Syntax - Declaration and instruction (C/C++)

- **Declare variables**

```
int capacity;
float height;
```

- **Declare and initialize variables (advised!)**

```
int capacity = 1;
float height = 0.5F;
char letter = 'A';
```

- **Instructions**

```
letter = 'A';
height = 0.5F* height + 1.0F;
++capacity;
```

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Delimiter for expressions is ';'

Base types (C/C++)

- The **Type** of a variable determine :
  - The set of possible values for a variable
  - The set of operations that can be applied to a variable
  - The size in memory required to store the variable

Typename	Minimal value	Maximal value
unsigned char	0	255
short	-32768	32767
int	-2147483648	2147483647
float	≈ -10^38	≈ 10^38
double	≈ -10^308	≈ 10^308

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Warning : not signed, if incremented after maximal value, fall back to zero !

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Warning : not signed, if incremented after maximal value, fall back to zero !

Warning : remember that floating point precision is not uniform !

Expressions (C/C++)

- **Expression**
  - Combination of values, variables, operators and function calls
  - Delimited by « ; »

- **Variable**
  - Mutable « value » identified by a name
  - Linked to a memory address and identified by a type to interpret memory content

- **Operator**
  - **Arithmetic:** +, -, *, /, %
  - **Relational:** >, >=, <=, ==, !=
  - **Logical :** &&, ||, !
  - **Increments :** ++, --
  - Bitwise (will be discussed in other lectures)

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Comment : Memory address of a variable can be seen as an abstraction of RAM memory address

Syntax - Explicit type conversion (cast)

- **Compute a ratio from integer numbers**

C

```c
int i = 2;
int j = 10;

double q = ((double) i) / j ;
```

C++

```cpp
int i = 2;
int j = 10;

double q = static_cast<double>(i) / j ;
```

Implicit type conversion (C++)

- **Widening conversions (promotion)**
  - signed, unsigned (not int64) -> double
  - bool, char -> any built-in type
  - short -> int, long, long long
  - int, long -> long long
  - float -> double
- **Narrowing conversions (coercion)**
  - floating point to integral types
  - int -> unsigned int
  - ...

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Implicit type conversion (C++)

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  - …

Comment : Narrowing conversions raise compiler warnings!

Syntax - Control flow

- **Conditions**

```
if (valeur==0 /* expression of the boolean condition */) {
  // Instruction 1;
  // Instruction 2;
  // …;

} else if (valeur==0 /* expression of another condition */) {
  // …;
} else { // if none of the above test passes
  // …;
}
```

- **NB: no « ; » after a control flow structure**

Syntax - Scopes

- **Scope of a variable = the block {} where it is defined**

```
{
  int i = 1;
  { // Beginning of Scope
    int j = 2;
    // can use i and j
  } // End of Scope
  // j does not exist anymore
}
```

- **Usual scopes :** control flow structure and functions

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Scope = sequence of instructions, of control flow structures and Scopes delimited by a pair of opening and closing brackets {}

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- **Usual scopes :** control flow structure and functions

Scope = sequence of instructions, of control flow structures and Scopes delimited by a pair of opening and closing brackets {}

Important : a variable cannot be used outside its scope of definition !

Syntax - Control flow

- **while loop**

```
int compteur = 0;
while (compteur < 10) {
  // Instructions…
  ++compteur;
}
```

- **for loop**

```
for (int compteur = 0; compteur < 10; ++compteur) {
  // Instructions…
}
```

Syntax - Control flow

```
for (int compteur = 0; compteur < 10; ++compteur) {
  // Instructions…
}
```

- **for loop, general case**

```
for (Decl. and init. ; End condition; End of iteration action) {
  // Instructions…
}
```

  - Declaration and initialization

```
int a=0, b=10
```

  - End condition

```
a>10 && b<0
```

  - End of iteration action

```
++a, b-=2
```

Syntax - Control flow

```
for (int compteur = 0; compteur < 10; ++compteur) {
  // Instructions…
}
```

- **for loop, general case**

```
for (Decl. and init. ; End condition; End of iteration action) {
  // Instructions…
}
```

  - Declaration and initialization

`int a=0, b=10`

  - End condition

`a>10 && b<0`

  - End of iteration action

`++a, b-=2`

Warning : beware of decrements and strict equality checks !

Syntax - Functions

- **Programme** = set of functions + entry point (main)
- **Minimal program**

C

```c
#include <stdio.h>

int main()
{
  printf("Hello World %!d", 2);
  return 0;
}
```

C++

```cpp
#include <print>

int main()
{
  std::print("Hello World {}!", 2);
  return 0;
}
```

Syntax - Functions

- **Programme** = set of functions + entry point (main)
- **Minimal program**

C

```c
#include <stdio.h>

int main()
{
  printf("Hello World %!d", 2);
  return 0;
}
```

C++

```cpp
#include <print>

int main()
{
  std::print("Hello World {}!", 2);
  return 0;
}
```

Comment : code outside of functions limited to declaration and initialization

Syntax - Function declaration

- **Return type** (or **`void`** if no value is returned)
- Parameter types for inputs
- Parameters are **copied** at call site !

C/C++

```c
#include <stdio.h>

int addition(int nombre1, int nombre2)
{
  return nombre1 + nombre2;
}

int main()
{
  printf("Hello World! »);
  printf("Hello World!");
  return 0;
}
```

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

```
int addOne(int x) {
  int y = x+1;
  return y;
}

int main () {
    int a;
    int b;
    a = 5;
    b = addOne(a);
    return 0;
}
```

IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a		10001
	b		10002
			10003
			10004
			10005
			10006
			10007
			...

IP = Instruction Pointer

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

```
int addOne(int x) {
  int y = x+1;
  return y;
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    int a;
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IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
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```

IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
	b		10002
addOne			10003
			10004
			10005
			10006
			10007
			...

How to handle a function call ?
=> Stack a new « frame »

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

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  int y = x+1;
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    b = addOne(a);
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```

IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
	b		10002
addOne	x	5	~~10003~~
			10004
			10005
			10006
			10007
			...

Param copy

Content of a « frame »

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

```
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  int y = x+1;
  return y;
}

int main () {
    int a;
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    a = 5;
    b = addOne(a);
    return 0;
}
```

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Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
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addOne	x	5	10003
			10004
	y		10005
			10006
			10007
			...

Alloc locals

Content of a « frame »

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- **Reminder :** variable passed as parameter to a fonction are copied

```
int addOne(int x) {
  int y = x+1;
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}

int main () {
    int a;
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    a = 5;
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    return 0;
}
```

IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
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			10006
			10007
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What to do ?

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

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  int y = x+1;
  return y;
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    b = addOne(a);
    return 0;
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```

IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
	b		10002
addOne	x	5	10003
	@return	10002	10004
	y	6	10005
			10006
			10007
			...

Save return address at call time !

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

```
int addOne(int x) {
  int y = x+1;
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}

int main () {
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IP

Frame	VAR	Pile	Adresse
main	...	...	...
	a	5	10001
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```

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main	...	...	...
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Copy

Memory organization - the stack

- **Reminder :** variable passed as parameter to a fonction are copied

```
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    b = addOne(a);
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}
```

IP

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main	...	...	...
	a	5	10001
	b	6	10002
			10003
			10004
			10005
			10006
			10007
			...

Unstack the frame when leaving the function

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Memory organization - the stack

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Memory organization - the stack

Important : memory of **local** variable is managed automatically !

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Memory organization - the stack

Important : memory of **local** variable is managed automatically !

Comment : can be optimized further by the compiler…

Syntax - Function declaration, definition and usage

```c
#include <stdio.h>

// Declaration of function (necessary before usage
// need to know the « contract »)
int addition(int nombre1, int nombre2);

// Definition of function (not necessary before usage)
int addition(int nombre1, int nombre2)
{
  return nombre1 + nombre2;
}

int main()
{
  printf("Result of 5 + 3 is %d \n", addition(5,3));
  //                                  ^^^^^^^^^^
  //                                  Using the function
 return 0;
}
```

Arrays (additional information on board)

- **Declaration (**allocation de N * sizeof(data_type) octets**)**

```
int tableau[4];
```

- **Initialization**

```
int tableau[4] = {10, 23}; // valeurs insérées : 10, 23, 0, 0
```

- **Usage**

```
tableau[0] = 10;
tableau[1] = tableau[0]+1;
```

Arrays (additional information on board)

- **Declaration (**allocation de N * sizeof(data_type) octets**)**

```
int tableau[4];
```

- **Initialization**

```
int tableau[4] = {10, 23}; // valeurs insérées : 10, 23, 0, 0
```

- **Usage**

```
tableau[0] = 10;
tableau[1] = tableau[0]+1;
```

Important : Beware when passed as parameter to function (pointer semantics)

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Libraries

- **Import declaration from functions** (#include)
- **Require linking** (will be rediscussed later)

- **Useful thing in C standard library** : math.h, string.h, …
- **… and a lot more in in C++ standard library…**

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Libraries

- **Import declaration from functions** (#include)
- **Require linking** (will be rediscussed later)

- **Useful thing in C standard library** : math.h, string.h, …
- **… and a lot more in in C++ standard library…**

Comment : in C++ new import keyword for modules …

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IMPORTANT

- **Read carefully compiler errors**
  - Ask for clarification if required !
- **Consider warning as errors**

- **Two main compilation mode**
  - **Debug** (option -g with gcc and clang)
  - **Release** (option -O2 or -O3 with gcc and clang)

- **the palest of ink is better than the best memory** (Chinese proverb)
  - Use a version control software => Git

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References

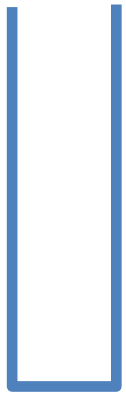
- en.cppreference.com
- learn.microsoft.com/en-us/cpp/cpp-language-reference

Notation polonaise inversé

- **Expression :** 2 x (4 + 3)
- **Peut s'écrire en NPI :** 4 3 + 2 x

- **Evaluation à l'aide d'une pile**

4 3 + 2 x



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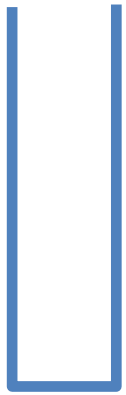
Constante : insert in LIFO



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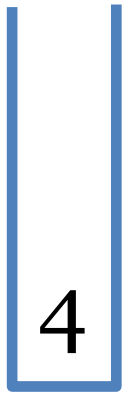

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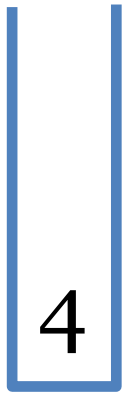

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Binary Operation :
- Pop operand 1 from LIFO
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4 3 + 2 x

Binary Operation :
Pop operand 1 from LIFO
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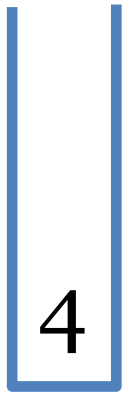
Compute operation
Insert result in LIFO

3



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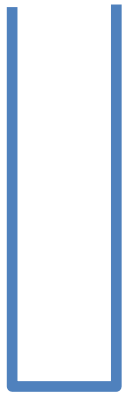
3
4



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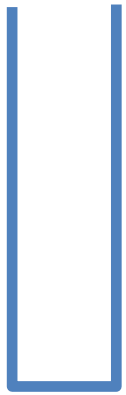
3
4
7



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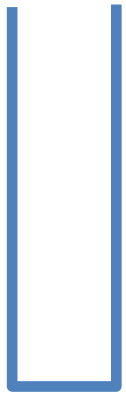

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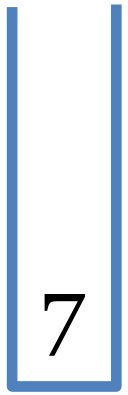

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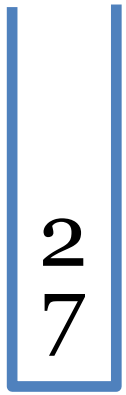

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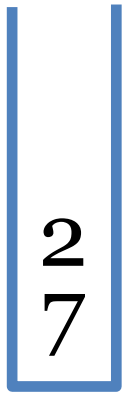

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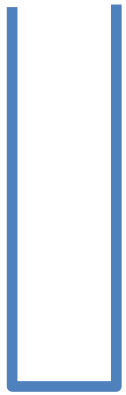

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- **Evaluation à l'aide d'une pile**

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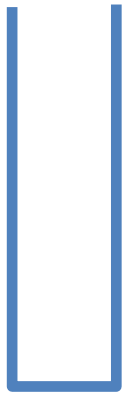
Binary Operation :
Pop operand 1 from LIFO
Pop operand 2 from LIFO
Compute operation
Insert result in LIFO

2
7
14



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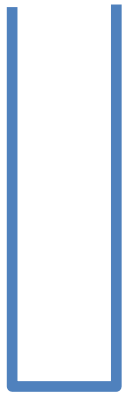

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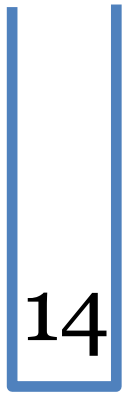

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- **Evaluation à l'aide d'une pile**

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Pop result

Notation polonaise inversé

- **Expression :** 2 x (4 + 3)
- **Peut s'écrire en NPI :** 4 3 + 2 x

- **Evaluation à l'aide d'une pile**

4 3 + 2 x

Pop result 14