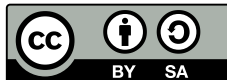
Introduction to Computing

The Art of Computer Programming

Pierre Senellart



15 September 2025

Outline

Introduction

Computing

Python, C, C++

Data representation

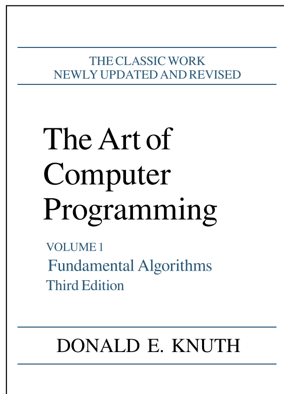
Variables

Expressions

Basic I/O

Coda

The Art of Computer Programming



Name of this course: Reference to a very famous book series (continuously written since the 1960s!) about algorithms by 1973 Turing award laureate Donald Knuth (b. 1938)

What you are going to learn: Computer programming, but not only; also introduction to:

- computing as a mindset
- algorithms, data structures
- evaluation of the quality of an algorithm
- basics of software engineering

Distinguishing factor: Focus on principles, good practices; instanciation to 2–3 programming languages: Python and C (along with a subset of C++)

Why does this matter?

- Understanding and designing AI systems require as much skill in maths as in programming, software engineering, and algorithms
- Critical to become fluent in programming to acquire a computing mindset: “How can I automate this?”, “How can I make this faster?”, “How to solve this problem step by step?”
- Some of you will specialize in fields where programming is a daily activity
- Some will not, but still need to be able to resort to programming as a tool
- LLMs are not a replacement for you learning to program: they may be good at some form of programming, but not at all, are susceptible to hallucinations, and relying on “vibe coding” means losing control of the system you are trying to design

This semester

Monday morning (09:00-12:15) Lectures & 10-min flash quizzes (wth Pierre Senellart)

Wednesday afternoons (14:00-17:15) Tutorials (exercise sessions) on your own computer (with Davide Carbone)

Monday November 10 1.5-hour mid-semester exam (before 1.5-hour lecture)

Monday February 2 2-hour final exam

Course evaluation

45% of the grade Final exam

35% of the grade Mid-semester exam

20% of the grade Weekly flash quizzes

Exercise sessions are not graded – but critical for you to practice.

Where to find help?

By order of priority:

- Refer to lecture materials (see the Moodle site)
- Check reference documentation (see links on Moodle)
- Ask us (Davide and Pierre)
- Discuss with your classmates
- Read/consult textbooks (see references further)
- Search on the Web, especially on Stack Overflow (but keep a critical mind!)

A note about LLMs

- LLMs are good about generating content that is similar to what they were trained on
- ⇒ they are usually quite good at simple programming exercises
- However:
  - you're not going to learn anything if you're asking LLMs to solve problems for you
  - their solution may be hard to understand
  - they may use programming language or algorithmic constructs outside of the scope of this class
  - they may occasionnally be just wrong (hallucinations)
- Not recommended, except in situations you are confident enough in your programming abilities to verify and fully understand their solution

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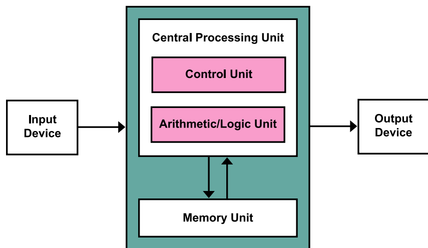
What is a computer?



Simplified architecture of a computer, as envisioned by John Von Neumann (1903–1957), one of the founding fathers of computer science.

- Device able to perform computation (*computer*), to process information (*informatics*), to control a computation process (*ordinateur*)
- Has to be programmable: its user can specify which (arbitrarily complex) computation to perform
- Must include:
  - A CPU that is able to perform computations and control the flow of the program
  - memory to store (short-term or long-term) the program itself, and data on which the computation is performed
  - input device through which both data and program are loaded
  - some form of output for the result

Digital electronic computer

- By far the most common form of computer nowadays
- Based on electronic components (transistors, capacitors, resistors, diodes, etc.) arranged in integrated circuits (aka, chips)
- Storage and processing of information based on digital binary signals (discretization of electric levels into 0s and 1s)
- Components:
  - a CPU, along with other integrated circuits (chipset, GPU, etc.) for computation, control flow, and management of other devices
  - random-access memory (RAM) for short-term memory storage (CPU cache, main RAM, video RAM) and solid-state or magnetic drives for long-term storage
  - keyboard, mouse, webcam, mike, and other peripherals for input
  - screen, printer, speakers, headphones and other peripherals for output
- Other technologies exist to design a computer:
  - Vacuum tubes
  - Quantum mechanics
  - molecular biology of DNA or RNA
  - etc.

Computer science, informatics

- The science of computation and information processing, i.e., the underlying aspects of what computers do
- Large variety of subfields, some close to mathematics, other closer to computer engineering:

  Calculability theory How can we define what is a computation, and which problems are computable?

  Algorithmics Given a problem, what is the "best" way to solve it in a systematic way?

  Machine learning How to train a system to generalize from examples and recognize patterns in data?

  Software engineering How to organize, maintain, test programs within large software collections?

  Human–Computer interaction How can we design efficient ways for humans to interact with a computer?

  Database management How to efficiently query and manage large data collections?

  ...

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- Programming is the way to transform (we say implement) an algorithm into code in a programming language, in order to execute the algorithm on concrete data

Algorithmics and Programming

- Every algorithm is implementable: it must be described in terms precise enough so that there is no ambiguity about how to transform it into a program
- ... but that does not mean that the program implementing the algorithm is easy to write, because the programmer must take into account machine limitations, language specifics, low-level objects rather than high-level concepts, etc.
- Algorithm: abstraction of what is implementable
- The programming language has no influence on what is implementable; all programming languages have the same expressive power (they are said to be Turing-complete as they have the same power as the abstract model of a Turing machine)
- ... but a language does have an impact on the ease (cf. `https://pierre.senellart.com/other/languages/languages.xml`) or on the efficiency of the implementation

Data structure

- A basic element used in more complex algorithms, reused in various algorithms to solve different problems
- Formal specification of an abstract mathematical object (list, set, graph, matrix, etc.), the possible operations on this object (insertion, enumeration, inversion, etc.), and the algorithms realizing them
- An implementable element, often in the form of a class in object-oriented programming
- It is often possible to design different data structures for the same mathematical object, more or less efficient for a given task

Who does what?

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- The software engineer integrates the program within a larger piece of software, tests it, validates it, stores it in a code repository

Example algorithm

Input: Array T with n distinct elements, an element x
Output: the position of x in T

1: **for** $i \leftarrow 0$ **to** $n-1$ **do**
2:     **if** $T[i] = x$ **then**
3:         **return** i
4:     **end if**
5: **end for**
6: **return** *not found*

Python Program

Python

```
def find(x):
    for i in range(0, n):
        if T[i] == x:
            return i
    return -1
```

Python Bytecode

```
          0 SETUP_LOOP              43 (to 46)
          3 LOAD_GLOBAL              0 (range)
          6 LOAD_CONST               1 (0)
          9 LOAD_GLOBAL              1 (n)
         12 CALL_FUNCTION            2
         15 GET_ITER
    >>   16 FOR_ITER                26 (to 45)
         19 STORE_FAST               1 (i)
         22 LOAD_GLOBAL              2 (T)
         25 LOAD_FAST                1 (i)
         28 BINARY_SUBSCR
         29 LOAD_FAST                0 (x)
         32 COMPARE_OP               2 (==)
         35 POP_JUMP_IF_FALSE       16
         38 LOAD_FAST                1 (i)
         41 RETURN_VALUE
         42 JUMP_ABSOLUTE           16
    >>   45 POP_BLOCK
    >>   46 LOAD_CONST               2 (-1)
         49 RETURN_VALUE
```

C Program

C

```
long find(int x) {
  for(long i=0; i<=1000; ++i)
    if(T[i]==x)
      return i;
  return -1;
}
```

x86-64 Assembly Code (compiled from C)

```
       push    rbp
       mov     rbp, rsp
       mov     DWORD PTR [rbp-20], edi
       mov     QWORD PTR [rbp-8], 0
.L5:   cmp     QWORD PTR [rbp-8], 1000
       jg      .L2
       mov     rax, QWORD PTR [rbp-8]
       mov     eax, DWORD PTR [rax*4+0x404060]
       cmp     DWORD PTR [rbp-20], eax
       jne     .L3
       mov     rax, QWORD PTR [rbp-8]
       jmp     .L4
.L3:   add     QWORD PTR [rbp-8], 1
       jmp     .L5
.L2:   mov     rax, -1
.L4:   pop     rbp
       ret
```

x86-64 Machine Code

```
      push   rbp                              #55
      mov    rbp, rsp                         #48 89 e5
      mov    DWORD PTR [rbp-20], edi          #89 7d ec
      mov    QWORD PTR [rbp-8], 0             #48 c7 45 f8 00 00 00 00
.L5:  cmp    QWORD PTR [rbp-8], 1000          #48 81 7d f8 e8 03 00 00
      jg     .L2                              #7f 1d
      mov    rax, QWORD PTR [rbp-8]           #48 8b 45 f8
      mov    eax, DWORD PTR [rax*4+0x404060]  #8b 04 85 60 40 40 00
      cmp    DWORD PTR [rbp-20], eax          #39 45 ec
      jne    .L3                              #75 06
      mov    rax, QWORD PTR [rbp-8]           #48 8b 45 f8
      jmp    .L4                              #eb 0e
.L3:  add    QWORD PTR [rbp-8], 1             #48 83 45 f8 01
      jmp    .L5                              #eb d9
.L2:  mov    rax, -1                          #48 c7 c0 ff ff ff ff
.L4:  pop    rbp                              #5d
      ret                                     #c3
```

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Programming languages

- Rich history of programming languages, from the 1950s onwards
- Many programming languages widely used and relevant today
- We focus on languages:
  - among the most important in history and nowadays
  - most useful for AI students
  - that illustrate well important computer science topics
- Once you are fluent in a programming language, learning new ones is much easier

Python

- Programming language initially designed by Guido van Rossum (Dutch programmer) in the early 1990s, now managed by the Python Software Foundation
- Major change in 2008 with the advent of Python 3.0, not backwards-compatible with previous Python versions; regular evolutions of the language since (most recent stable version in September 2025 is 3.13)
- High-level language, with a focus on code readability, over the ability of being close to low-level machine code and raw efficiency
- Several existing implementations of Python but the reference one and most commonly use by far, CPython (free and open source software), use compilation to bytecode, then interpretation of the bytecode
- 2025 Stack Overlow developer survey: 2nd most popular programming language among developers (after JavaScript)
- By far the programming language of reference for data science applications

C

- Programming language initially designed by Dennis Ritchie (American computer scientist and 1983 Turing award laureate), now standardized by a committee of the International Standard Organization (ISO)
- Major new standards in 1999 (C99), 2011 (C11), and 2023 (C23) – we will mostly use features of C11
- Low-level language, with a focus on efficiency and precise memory management
- Several existing implementations (all through direct compilation to machine code), including GCC, Clang (both free and open source software), and Microsoft Visual C++ (free to use in Visual Studio under Windows)
- 2025 Stack Overlow developer survey: 6th most popular programming language among developers (after JavaScript/TypeScript, Python, Java, C#, C++)
- Language of reference for embedded applications and other low-level development (e.g., in operating systems)

C++

- Programming language initially designed by Bjarne Stroustrup (Danish computer scientist), now standardized by a committee of the International Standard Organization (ISO)
- Major new standards in 1998 (C++98), 2011 (C++11), 2017 (C++17), and 2020 (C++20) – we will mostly use features of C++17
- Designed to keep C's low-level features, focus on efficiency and precise memory management, along with high-level programming features (object-oriented programming, generic programming, etc.); C is *almost* a subset of C++
- Very rich and complex programming language, we will only see a small fractions of its features, mostly to complement C
- Several existing implementations (all through direct compilation to machine code), including GCC, Clang (both free and open source software), and Microsoft Visual C++ (proprietary software)
- Very popular language for applications where both performance and high-level features are important (e.g., video game engines, deep learning models)

A Python, C, C++ program

- Programs are written as plain-text files, with any text editors (Notepad, Emacs, Vim, TextEdit, Sublime Text, etc.) or integrated development environements (IDE, such as Visual Studio Code, Eclipse, Xcode) – we will use Visual Studio Code (free and open source, available under Windows, Mac OS, Linux) in tutorials
- One program: one or more such text files, possibly along with other files
- Python, C, C++ programs can use functionalities provided by their standard library (a library of functions accompanying the core language) or from third-party libraries (programs developed by others and meant to be integrated within a user's code)
- Programs can include a main function, which defines the code that will be executed when the program is launched; optional in Python (by default, everything in the file is run), required in C and C++
- Programs are formed as a succession of statements or instructions. In Python, newlines complete a statement; in C or C++ the statement is completed by a final semicolon (`;`) and line breaks are irrelevant

Importing library functionalities

To use a feature from a library *mylibrary* from the standard library, one need to add (usually at the beginning of a file) declarations such as:

Python

```python
import mylibrary
```

C

```c
#include <mylibrary.h>
```

C++

```cpp
#include <mylibrary>
```

Comments

A program may include comments, which is just text meant for a human reader, which does not impact the compiler or interpreter in any way.

- In Python, everything that starts with # till the end of the line is a comment
- In C and C++, everything that starts with // till the end of the line is a comment
- In C and C++, everything in between /* and */ (possibly spanning multiple lines) line is a comment

"Hello world" in different languages

Python

```python
print("Hello world") # This is a comment.
```

C

```c
#include <stdio.h>

int main(void) {
  printf("Hello world\n"); /* This is a comment. */
  return 0;
}
```

C++

```cpp
#include <iostream>

int main() {
  std::cout << "Hello world" << std::endl; // This is a comment.
  return 0;
}
```

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Refresher: Bases

- We usually work in base 10 (decimal), but other bases, notably 2 (binary) and 16 (hexadecimal), are often more convenient to deal with data in digital electronic computers; we occasionally write the basis as $\underline{\text{number}}_{\text{basis}}$

  Decimal base Digits are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

  Binary base Digits are 0, 1

  Hexadecimal base Digits are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
- By definition, $\underline{42}_{10} = 2 \times 10^0 + 4 \times 10^1$
- Similarly:
  - $\underline{101010}_2 = 0 \times 2^0 + 1 \times 2^1 + 0 \times 2^2 + 1 \times 2^3 + 0 \times 2^4 + 1 \times 2^5 = 2^1 + 2^3 + 2^5 = 2 + 8 + 32 = \underline{42}_{10}$
  - $\underline{42}_{16} = 2 \times 16^0 + 4 \times 16^1 = 2 + 64 = \underline{66}_{10}$
  - $\underline{\text{BF}}_{16} = 15 \times 16^0 + 11 \times 16^1 = \underline{15}_{10} + \underline{176}_{10} = \underline{191}_{10}$
- Note that a hexadecimal number with n hexadecimal digits transforms into a binary number with $\leqslant 4n$ binary digits

Binary data

- Digital electronic computers manipulate bits (or binary digits), i.e., every piece of information is formed of 0s and 1s
- Since a single bit is not much, bits are grouped together in larger structures:

  Byte sequence of 8 bits (or two hexadecimal digits!)

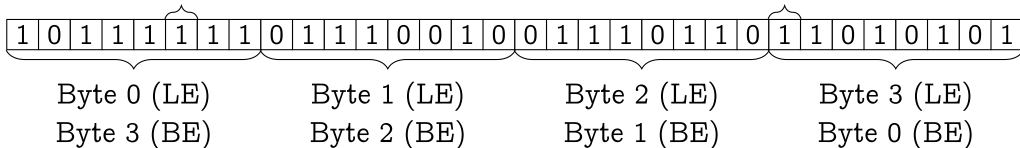
  Multibyte word a sequence of multiple bytes; e.g., a processor has a native data size; e.g., in 64-bit architectures (most common nowadays), a native word is 64 bits, or 8 bytes
- Within a byte, bit 0 is the least significant; bit 7 is the most significant (e.g., 11000010 is a binary representation of the decimal number 194 with bits 1, 6 and 7 set to 1 and the rest to 0)
- Within a word, the most significant byte depends on the endianness of the architecture:

  Little-Endian (LE) architecture the first byte is the least significant (most common)

  Big-Endian (BE) architecture the first byte is the most significant one (rare)

Endianness example

Example (32-bit word)



Binary data representations

- In programs, one want to manipulate data that is more complex than just bits or binary words, starting with:
  - integers (nonnegative or arbitrary), for counters, indices, etc.
  - approximations of real numbers for numerical computations
  - text , in the form of characters or finite sequences of characters (called character strings)
- How are these data represented as binary data?
- Also, more complex data types; we will cover them in a later lecture

Booleans

- George Boole: 19th century mathematician who came up with an algebra of truth values
- Boolean: a representation of a truth value, either True or False
- Often natural outcome of data processing; e.g., checking whether two integers is equal results in a Boolean value
- Binary representation is trivial: just use a bit!
    - 1 means True
    - 0 means False

Unsigned integers

- Nonnegative integers are called unsigned integers in computing
- Two strategies:
  - Fix an upper limit on the value of the integer (aka fixed-size unsigned integers), say $2^k - 1$
    - All integers between 0 and $2^k - 1$ can be represented as a sequence of k bits; k is usually chosen to be a multiple of 8, to have whole bytes

Bits	Bytes	Range of integer
8	1	0 to 255
16	2	0 to 16 383
32	4	0 to 4 294 967 295
64	8	0 to 18 446 744 073 709 551 615

    - Advantage: the CPU already knows how to add, multiply, divide, etc., unsigned integers of 8, 16, 32, or 64 bits
  - Allow integers of arbitrary value (aka arbitrary-size unsigned integers) – but then:
    - the number of bits required to represent them is not fixed any more
    - Arithmetic is more expensive, does not map to a single CPU operation

Signed integers

- Arbitrary integers are called signed integers in computing
- Several ways of representing the sign of the integer n:
  - Sign–Magnitude: represent the absolute value $|n|$ using unsigned integer binary representation, and add one bit to indicate whether $n = +|n|$ (bit $= 0$) or $n = -|n|$ (bit $= 1$)
    - Quite simple!
    - Problem: 0 has two representations $+0$ and -0
    - With k bits, can represent integers between $-2^{k-1} + 1$ and $2^{k-1} - 1$
  - Two-complement: zero and positive numbers are represented as unsigned numbers; to represent a negative number $-n$, first compute n, then invert all bits, then add one to the result, with regular addition on binary numbers. With k bits, can represent integers between $-2^{-k-1} + 1$ and 2^{k-1}.

    For example, using 8 bits:

Binary representation	Number
00101010	42
11010110	-42

- Modern CPUs already know how to add, multiply, etc., signed integers with two-complement representation of common sizes

Floating-point numbers

- Impossible to represent an arbitrary real number (with infinite decimal expansions) using a finite representation
- Note that rational numbers can be represented as pairs of integers (numerator and denominator)
- For numerical computation, possible to store a floating-point number: an approximation of a real number inspired by scientific notation (e.g., $6.02214076 \times 10^{23}$ a fixed number of significant digits, and an exponent)
- IEEE-754: standard explaining how to do this using 32-bit, 64-bit, 128-bit floating-point numbers
- In IEEE-754, the number of significant digits is of decimal digits, but the exponent will be of the form 2^e
- For example, for an IEEE-754 32-bit representation:

Original decimal number	$6.02214076 \times 10^{23}$
IEEE-754 32-bit representation	0 11001101 11111110000110000101110
Meaning of the representation	$(+1) \times 2^{205-127} \times (1 + 0.992559194564819 3)$
Actual value of the representation	$\approx 6.02214064 \times 10^{23}$

Character sets

Unicode: character repertoire, assigning to each character, whatever its script or language, an integer number.

Examples

A	$\to$	65	ε	$\to$	949
é	$\to$	233	ۃ	$\to$	1731

Character encoding: concrete method for representing a Unicode character.

Examples (é)

iso-8859-1	11101001	only for some characters
utf-8	11000011 10101001	
utf-16	11101001 00000000	

utf-8 has the advantage of being able to represent all Unicode characters, in a way compatible with the legacy ASCII encoding (that specifies how to represent the first 128 characters of Unicode). However, depending on the character, a UTF-8 representation of it may take anywhere between 1 and 4 bytes.

Characters and character strings

- We fix a character encoding (usually utf-8, but not always)
- A character is represented by the sequence of bytes for this character in this character encoding
- A character string is represented by:
  - The sequence of bytes representing each character, one after the other
  - Some way to determine where this sequence terminated, either:
    - A representation of the unsigned integer listing either the number of characters or the number of bytes
    - A special byte put after all other bytes indicating the character string is finished (usually the null byte 00000000)
- The length in bytes of a character string is not the length in characters of this character string!
- ASCII characters (first 128 characters of Unicode, including Latin alphabet lowercase and uppercase letters, Arabic numerals, most common punctuation sign and special characters) are encoded as one byte in most (but not all!) character encodings, including utf-8; so if one is sure that a string only contains ASCII characters, its byte and character lengths are equal

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Variables in programming languages

- Not the same as a variable in mathematics!
- A variable is a named memory location containing a value of some type
- A variable has:

a name
: used to refer to that particular variable

an address
: i.e., an integer indicating the location of the variable in the memory of the computer (through a mapping maintained by the operating system or interpreter of addresses to actual physical locations)

a type
: specifying which data representation to use to interpret the value of the variable

a value
: the actual interpretation (for the variable type) of the data stored at the variable address

a scope
: which indicates from which part of the program the variable can be referred to

an extent
: which indicates the lifespan of the variable

Typing in Python, C/C++

- C and C++ are strongly typed languages: once a variable is declared with a type, its type can never change (the type and address of a variable never changes over its extent)
- Python is a weakly typed language: a variable may first be assigned a value of some type, then a value of another type (so both the type and address of a variable may change over time)
- C and C++ are statically typed languages: the type of a variable is fixed at the moment the variable is first declared (either by explicitly specifying the type, or – in C++ and very recent versions of C – by letting the compiler inferring it from context)
- Python is a dynamically typed language: the type of a variable is just the type of whatever value is assigned to the variable
- Note: Python can be turned into a statically typed language using type annotations and external tools such as `mypy` – we will not cover this

Defining and assigning variables

- Python, C, C++ all use the *name* = *value* syntax to assign a value to a variable
- In C/C++, the first time a variable is used, it needs to be defined by prefixing the name with a *type*
- The value of a variable can be used by simply using the variable name on the right-hand side of an assignment

Python

```python
i = 42
i = 'Hello'
j = 4.5
j = i
```

C

```c
int i = 42;
i = 54;
const char* s = "Hello";
double d = 4.5;
```

Primitive types in Python

Type	Example literal values	Note on representation
`bool`	`True False`	
`int`	`123 +123 123_456 -42 0b1111 0xABCD`	arbitrary-precision signed integer
`float`	`3.14159 +6.02e23`	64-bit IEEE-754
`str`	`'Hello' "Hello" 'Ça va?' """Long "text"."""`	utf-8 character strings with length
`complex`	`42j`	pair of `floats`

- No difference between `'Hello'` and `"Hello"`
- To type a single quote character within a single-quoted string, or a double quote character within a double-quoted string, prefix it with a backslash: `"\""`, `'\''`
- Strings enclosed with `"""..."""` can include line breaks

Primitive types in C, C++ (1/2)

Type	Example literal values	Note on representation
`bool`	`true false`	
`int`	`123 +123 123'456 -42 0xABCD`	signed integer of default size
`unsigned`	`123u 123'456u 0xABCDu`	unsigned integer of default size
`long`	`123l +123l 123'456l -42l 0xABCDl`	signed integer of longer size
`unsigned long`	`123ul 123'456ul 0xABCDul`	unsigned integer of longer size
`long long`	`123ll +123ll 123'456ll -42ll`	signed integer of even longer size
`unsigned long long`	`123ull 123'456ull 0xABCDull`	unsigned integer of even longer size
`short`		signed integer of shorter size
`unsigned short`		unsigned integer of shorter size

- What default, longer, even longer, shorter means is not defined by the standard, depends on the CPU, operating system, compilation environment; may be for example 32, 64, 64, 16 bits
- For this reason, C/C++ also provides precise data types `int8_t int16_t int32_t int64_t uint8_t uint16_t uint32_t uint64_t` that guarantee the size to be respectively 8, 16, 32, 64, 8, 16, 32, 64 bits

Primitive types in C, C++ (2/2)

Type	Example literal values	Note on representation
`float`	`3.14159f +6.02e23f`	32-bit IEEE-754
`double`	`3.14159 +6.02e23`	64-bit IEEE-754
`long double`	`3.14159l +6.02e23l`	"longer" floating-point number
`char`	`'A' '9'`	Byte
`const char*`	`"Hello"`	Byte sequence

- To type a double quote character within a `const char*` string, prefix it with a backslash: `"\""`
- `char` and `const char*` are about bytes, not characters, despite their names – they are suitable for ASCII character (strings); to use `const char*` for arbitrary (utf-8) strings, the character encoding needs to be manually managed

Type and address of a variable

- In Python, `type(variable)` returns a description of the type of the variable `variable`
- In C/C++, this is not required as the type is known statically
- In Python, `id(variable)` returns the address of the variable `variable` as an integer
- In C/C++, `&variable` returns the address of the variable `variable` of type `vartype` as a value of type `vartype*` (called a pointer to a vartype); if one has an address `addr` of type `vartype*`, `*addr` returns the value at the address `addr`
- One can also use `*addr` as the left-hand-side of an assignment: `*addr = val` changes the value pointed to by `addr` to `val`

Example use of pointer

C

```c
int i = 42;  // i is assigned the integer value 42
int* p = &i; // p is assigned the address of i
int j = *p;  // j is assigned the value at the address p, i.e., 42
*p = 121;    // We modify the value at the address p to 121
int k = i;   // k is set to the value of i, now 121
```

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Expressions

- Everywhere a value is expected (e.g., on the right-hand side of an assignment), one can use an expression instead, made from variables and values
- This expression may include operators such as +, *, /, or call to functions such as `len()`
- As the expressions of Python are largely inspired from C, many operators are common to all three languages
- Arguments to function calls or expressions can themselves be arbitrary expressions
- As in maths, there are precedence rules to determine in which order operators are evaluated (e.g., multiplication before addition) but parentheses can be used to remove any ambiguity
- The type of an expression is the type of the value returned by this expression

Comparison operators

Operator	Example	Meaning
`==`	`i == 42`	equal to
`!=`	`i != 42`	not equal to
`<`	`i < 42`	less than
`<=`	`i <= 42`	less than or equal to
`>`	`i > 42`	greater than
`>=`	`i >= 42`	greater than or equal to

- These operators take expressions of the same types
- Cannot be used for comparing `const char*` byte sequences in C/C++
- These operators return `bool` values (or in the case of C, 0 or 1 integer values that can be transparently used as `bool`)
- Python also has operators `is` and `is not` which are synonymous for address (in)equality : `a is b` iff `id(a) == id(b)`

Boolean operators

Python Operator	Example	Meaning
`not`	`not (i == 42)`	not
`and`	`(i != 42) and (i != 21)`	and
`or`	`(i == 42) or (i==21)`	or

C/C++ Operator	Example	Meaning
`!`	`!(i == 42)`	not
`&&`	`(i != 42) && (i != 21)`	and
`||`	`(i == 42) || (i==21)`	or

- These operators take `bool` and return `bool` values (or in the case of C, 0 or 1 integer values that can be transparently used as `bool`)

Arithmetic operators

Operator	Example	Meaning
`+`	`i + 42`	addition
`*`	`i * 2.0`	multiplication
`-`	`-i`	substraction (or unary minus)
`/`	`i / 42`	division
`%`	`i % 42`	remainder of integer division
`//`	`i // 42`	integer division (Python only)
`**`	`2 ** 8`	exponentiation (Python only)

- These operators take expressions of the same numeric (integer or floating-point) types (or types that can be converted to the same type) and return a value of the same type
- In C/C++, / is the integral division if both arguments are integers, the floating-point division otherwise; in Python, it is always the floating-point division

Mathematical functions in Python

- Requires `import math`
- Powers and roots:
  - `math.sqrt(x)`, `math.pow(x, y)`, `math.exp(x)`
- Logarithms:
  - `math.log(x)` (natural), `math.log10(x)`, `math.log2(x)`
- Trigonometry:
  - `math.sin(x)`, `math.cos(x)`, `math.tan(x)`
  - Inverses: `math.asin(x)`, `math.acos(x)`, `math.atan(x)`
- Other:
  - `math.fabs(x)`, `math.floor(x)`, `math.ceil(x)`

Mathematical functions in C/C++

- Requires #include <math.h> (C) or #include <cmath> (C++)
- Powers and roots:
  - sqrt(x), pow(x, y), exp(x)
- Logarithms:
  - log(x) (natural), log10(x)
- Trigonometry:
  - sin(x), cos(x), tan(x)
  - Inverses: asin(x), acos(x), atan(x)
- Other:
  - fabs(x), floor(x), ceil(x)

String functions in Python

- `len(s)` returns the number of characters in `s`
- Strings can be compared with standard Python comparison operators
- `s1 + s2` is the concatenation of the two strings (all characters of `s1` followed by all characters of `s2`)
- `s * n` is the string where `s` is repeated `n` times

String functions in C

- Requires `#include <string.h>`
- `strlen(s)` returns the number of bytes in s
- `strcmp(s1,s2)` compares s1 and s2: returns 0 if identical, -1 or 1 otherwise depending on whether s1 comes before or after s2 in lexicographic order
- C++ has better functionalities for character strings (or for byte sequences), will be discussed in a further lecture

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Basic input and output

- A program often needs to interact with a user
- Can be very complex graphical, audio, video interfaces
- We are going to consider very simple text-based interfaces used within a program: a user can enter simple data in a text console, and the program can output simple character strings

Basic input in Python

Python

```
s = input()
# s will contain the string typed by the user
i = int(s) # convert the string to an integer
```

Basic input in C

C

```c
int i = 0;
scanf("%d", &i);
// i will contain the integer typed by the user
```

Basic output in Python

Python

```
name = 'Pierre'
age = 44
print(f"Your name is {name} and you are {age} years old.")
```

These are called f-strings. Every expression within curly braces is evaluated and replaced in the string with its value. (Use double curly braces if you want to write an actual curly brace character.)

Basic output in C

C

```
const char* name = "Pierre";
int age = 44;
printf("Your name is %s and you are %d years old.", name, age);
```

- Requires `#include <stdio.h>`
- See the documentation of `printf` to output other types of data

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Reference material

- Purely optional! If you want to deepen your understanding of some concepts. Goes into much more depth than this course.
- For programming languages, textbooks and tutorials are helpful to learn the language; reference documentation is useful for beginners and experienced programmers alike, to look some concept or function up

Programming	Wassberg [2020]
Algorithms	Cormen et al. [2009]
Python	Lutz [2025] and `https://docs.python.org/3/`
C	King [2008] and `https://en.cppreference.com/w/c.html`
C++	`https://www.learncpp.com` and `https://en.cppreference.com/`

More about digital electronic computers

- How everyday computers are actually implemented down to the electronic and physical level is a fascinating subject
- No time to cover this in class
- But if you are interested, check the following games:
  - NandGame
    `https://nandgame.com/`
  - Turing Complete
    `https://store.steampowered.com/app/1444480/Turing_Complete/`
  - Hard Chip
    `https://store.steampowered.com/app/2844290/Hard_Chip/`

In preparation for Wednesday's tutorial

If possible, to gain time for Wednesday's tutorial:

- Install Visual Studio Code on your computer, see `https://code.visualstudio.com/download`
- Install a Python environment and Python extensions for Visual Studio Code, see `https://code.visualstudio.com/docs/python/python-tutorial`
- Install a C/C++ compilation environment and C/C++ extensions for Visual Studio Code, see `https://code.visualstudio.com/docs/languages/cpp`

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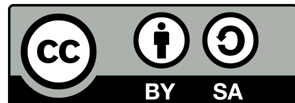

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