LIÈGE université
GIGA

Introduction to computer science:

historical perspective, computer structure, operating systems & languages

GIGA Doctorate School

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Program

- Historical perspective
- Computer structure
- Operating systems
- Programming languages

Some wisdom…

"1. Start simple. 2. Get it to work. 3. Then, add complexity."

- Tom Bredemeier

"One of the best programming skills you can have is knowing when to walk away for awhile."

- Oscar Godson

https://twitter.com/CodeWisdom

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Historical perspective

Computer science did NOT suddenly appear during World War II out of a genius mind.

Three parallel streams:

- Calculation instruments, from abacus to Pascal's mechanical calculator
- Mathematical logic, from al-Khwarizmi (VIII^th century) to Alan Turing (XX^th century)
- Automats, from antiquity (e.g. Hero of Alexandria's 1^st vending machine) to 'Jacquard loom', and great watch & clock makers

Historical perspective

- 1837, the “Analytical Engine”, described by **Charles Babbage**

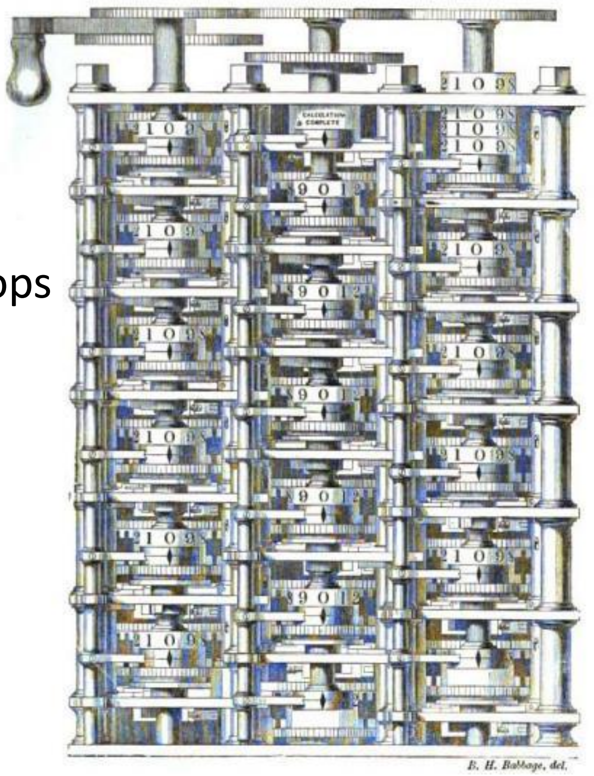
  = 1st mechanical general-purpose computer, including:

  - arithmetic logic unit + integrated memory
  - control flow in the form of conditional branching and loops

- 1843, “algorithm” for the Analytical Engine, by **Ada Lovelace**

  = 1st software (to calculate Bernoulli numbers)

  - set of instructions to solve problems of any complexity
  - symbolic representation by numbers of letters, musical notes, etc.

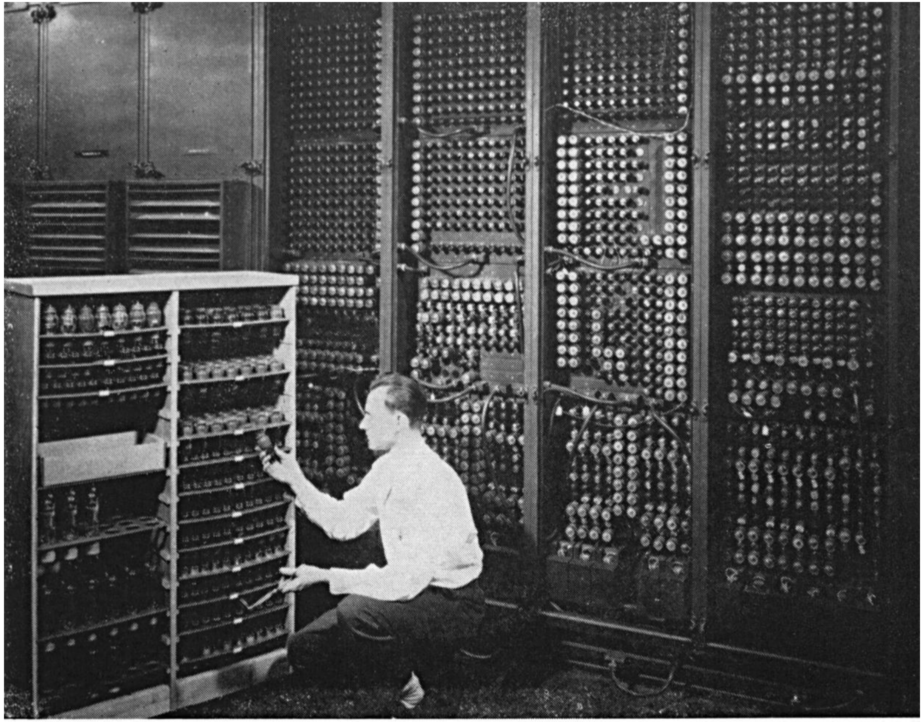


Historical perspective

- 1943-1945, Colossus computer, UK.
- 1945-1956, ENIAC (Electronic Numerical Integrator and Computer), USA.

Programs hard coded into the machines with 10000's of switches and plugs!

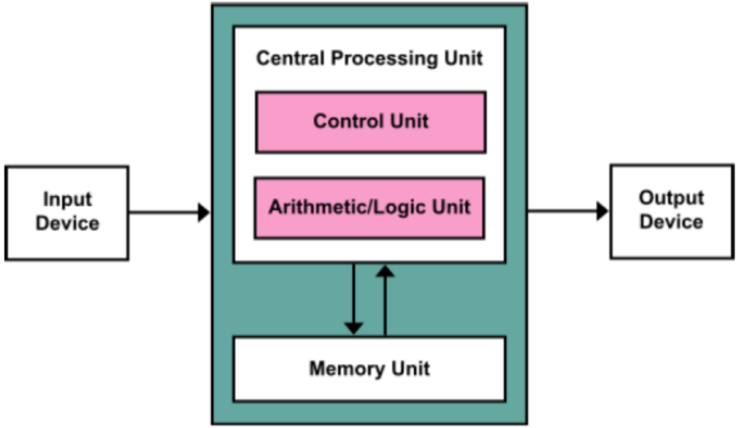
(…and bugs were real!)



Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

Von Neumann architecture

- Proposed by Von Neumann in 1945
  (unifies Babbage's Analytical Engine
  and abstract Turing machine)

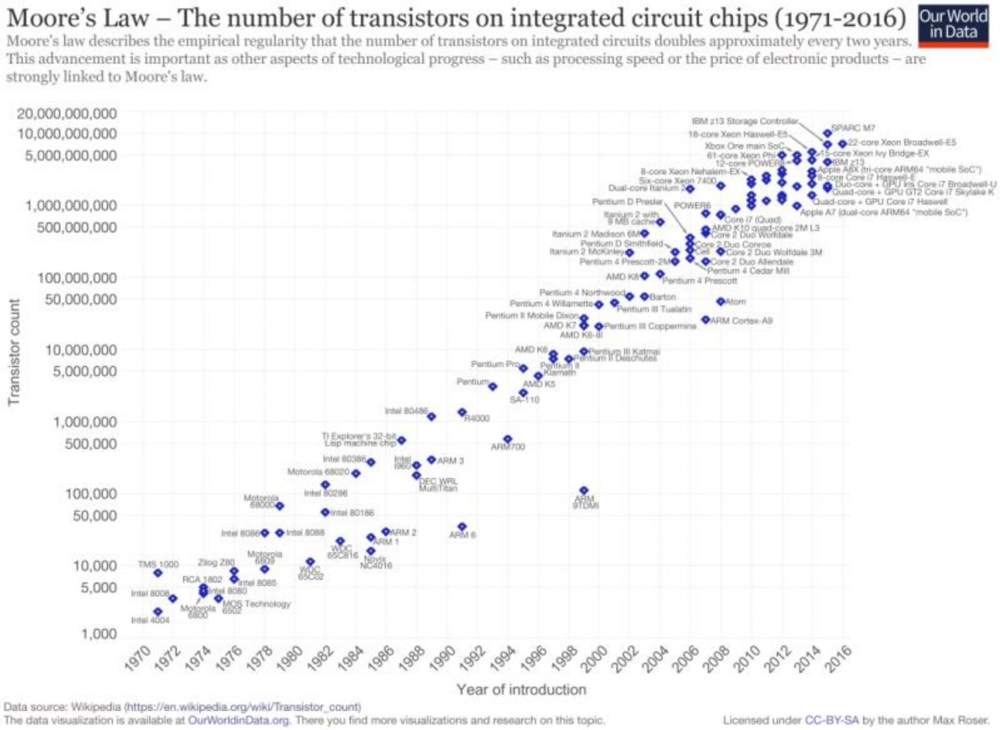


- Fundamental ideas:
  - Bring *input*, *output* and *program* in "memory unit"
  - Operate only on this memory

→ Stored-program computer keeps both <u>program instructions</u> and <u>data</u> in read-write, "random-access memory" (RAM)!

Hardware innovations

- In the 1950's & 1960's, tubes are replaced by transistors then integrated circuits.
  → higher density + more reliable
  + less energy consumption (heat!)



- In 1965, Moore's law:

The number of transistors in an IC doubles every 18 months!

Mainframes vs. mini-computers

1960’s & 1970’s, development of :

- mainframes
  - Large centralised infrastructure
    → high performance
  - Passive terminals
    → submit ‘batches’
- mini-computers
  - All-in-one machine
    → direct interaction
  - Small and cheap (actually still pretty big and expensive…)

IBM mainframe at NASA

Micro-computer

In 1971, first Intel microprocessor

→ All main elements of a computer in 1 integrated circuit
& no wiring, except on 'motherboard'

→ the **micro-computer**

In 1975, Altair 8800 (Bill Gates & Paul Allen)
& Apple 1 (Steve Jobs and Steve Wozniak)

Personal Computer (PC)

- 1977, TRS-80
- 1979, Apple 2 with 1st spreadsheet software
- 1982, Commodore 64 → gaming
- 1982, IBM-PC with
  - Intel "x86" architecture (still used now)
  - MS-DOS from Microsoft

Software industry

- Software, originally part of the computer and thus “free”
- Increasing distinction between “hardware” and “software”
- Since the 70’s a 80’s, more standardized hardware

  → standardized and specific software:

  - operating system: Unix, MS-Dos (later on Windows), Macintosh System 1 (later on Mac OS), Linux,...
  - applications: spreadsheet, text editing, games, image & audio processing, high-level programming,...

Algorithm

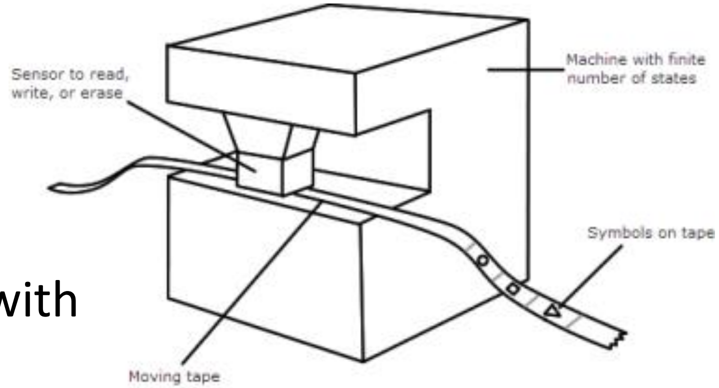
Definition:

an algorithm is an unambiguous specification of how to solve a class of problems.

An algorithm

- expressed within a finite amount of space and time
- in a well-defined formal language for calculating a function.
- starting from an initial state and initial “input”,
- the instructions describe a computation that, when executed, proceeds through a finite number of well-defined successive states,
- eventually producing “output” and terminating at a final ending state.

Turing machine



The (abstract) Turing machine models a <u>machine</u> with

- tape = infinite series of cells with 1’s or 0’s
- control unit = finite set of elementary instructions
- Input/output = to read, write or move the tape

Example: *“in state 42, if the symbol seen is 0, write a 1; if the symbol seen is 1, change into state 17; in state 17, if the symbol seen is 0, write a 1 and change to state 6; etc.”*

Given any computer algorithm, a Turing machine capable of simulating that algorithm's logic can be constructed.

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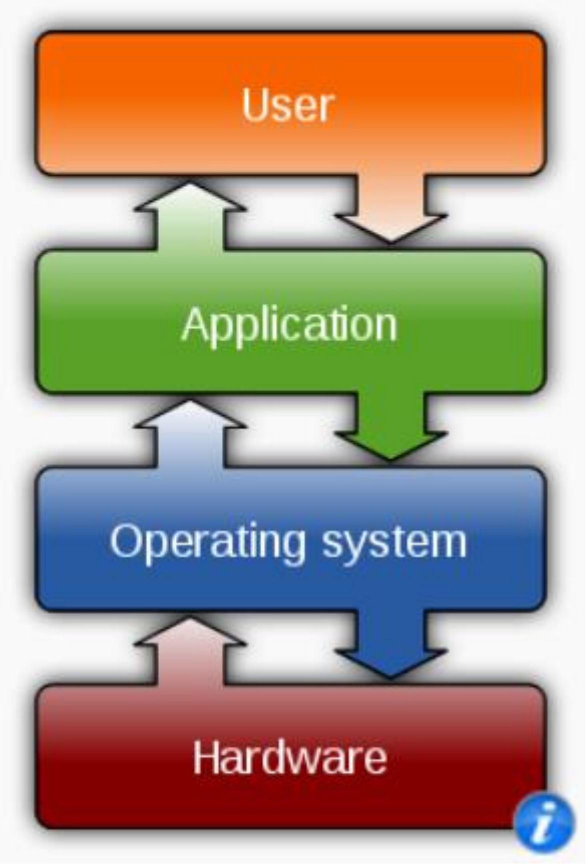
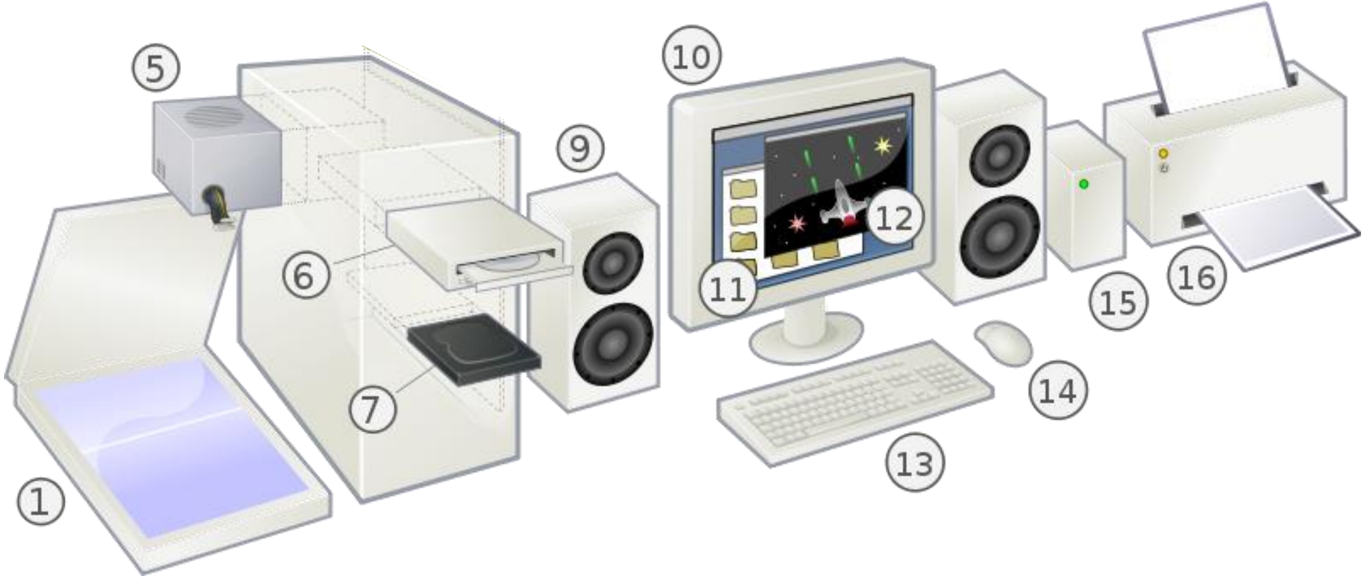
- Languages



Outside the “motherboard”

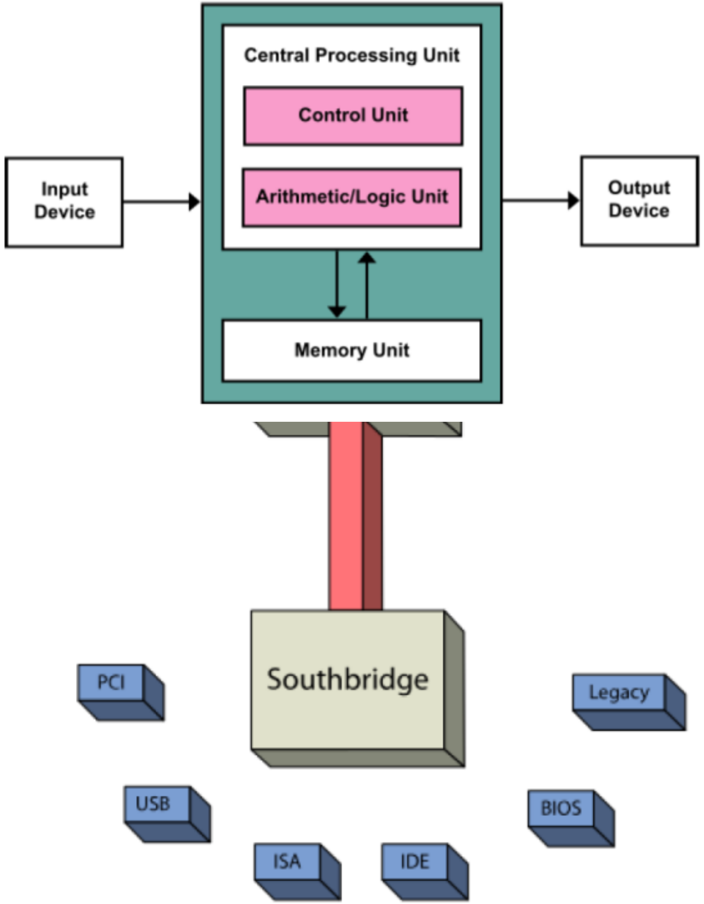
Peripherals:

screen, keyboard, mouse, speaker, printer, scanner, power supply,… plugged to the “motherboard”



The "motherboard"

- CPU = microprocessor
  - executes the instructions.
  - includes very fast local memory locale, aka "cache"
- RAM = central memory
  - quickly read/write instructions and data
  - lost when power is off
- GPU (*Graphics Processing Unit*)
  - like CPU but parallelized infrastructure
  - generates and stores image frames
- Northbridge = connecting fast components
- Southbridge = handles slower input/output
  - hard-drives (internal/external)
  - USB peripherals (keyboard, mouse, USB stick,...)
  - network connexions, incl. Wi-Fi & cable
- Inter-connexion through "data bus"



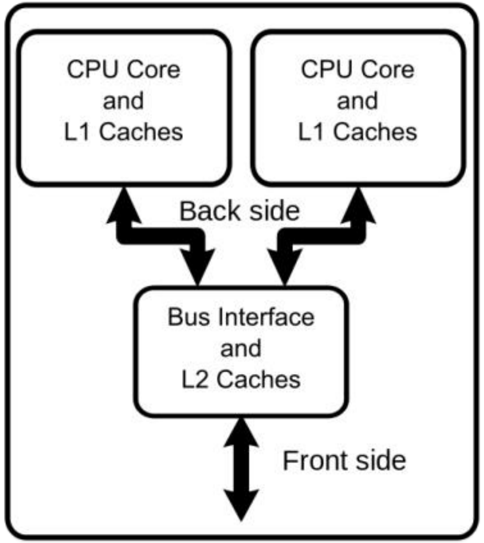
Different types of memory

- RAM,
  - fast but not persistent $\rightarrow$ used by microprocessor (data & operations)
  - limited to a few Gb
- Hard drive
  - slower but persistent $\rightarrow$ used to store data, code, OS
  - up to several Tb
- Cache
  - inside the CPU $\rightarrow$ super fast but built in
- ROM/BIOS (Basic Input Output System)
  - boot firmware and power management firmware

Faster & more power

Get some

- multi-core processor
- higher clock speed
- larger RAM
- faster data transfer



Caveats

- need specific software/compiler to parallelize operations
- depend on nature of data and processing pipeline
- depend on mass-storage solution (access & r/w time!)

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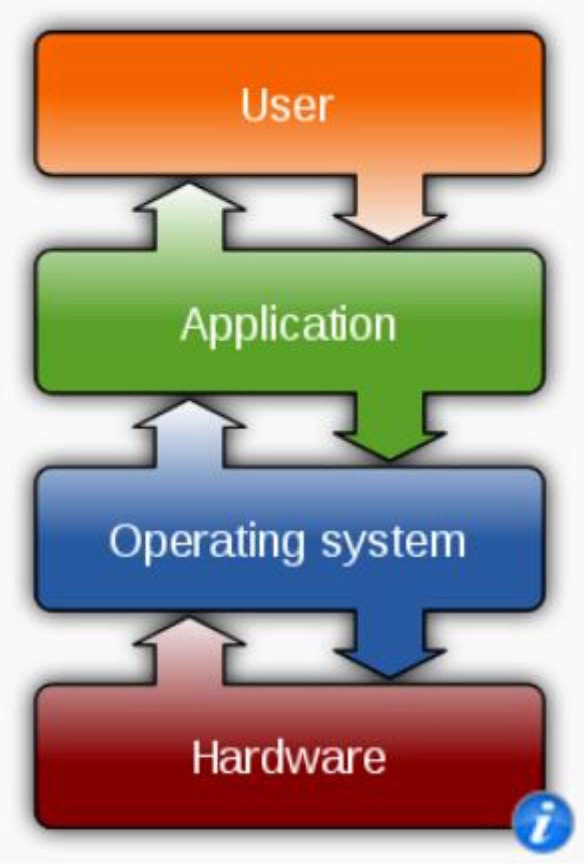
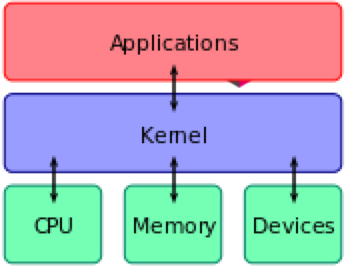




OS definition

An “**operating system**” (OS)
= system fundamental software to

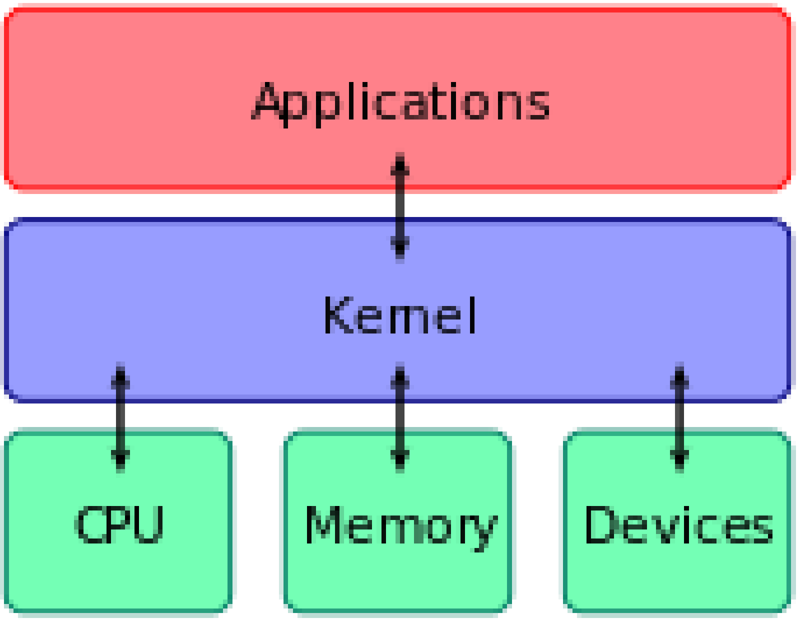
1. manage computer hardware and software resources, and
2. provide common services for computer programs:

OS tasks

- **Process management**.
  allocate resources to processes, enable processes to share and exchange information, protect the resources of each process from other processes and enable synchronization among processes
- **Memory management**.
  management of computer memory resource
- **File system**.
  controls how data is stored and retrieved
- **Device drivers.**
  operates or controls a particular type of device attached to a computer
- **Networking.**
  allows “nodes” to share resources
- **Interrupts**.
  signal to the processor emitted by hardware or software indicating an event that needs immediate attention
- **Security.**
  protection of computer systems from theft or damage to their hardware, software or electronic data, as well as from disruption or misdirection of the services they provide
- **I/O.**
  communication between an information processing system, such as a computer, and the outside world, possibly a human or another information processing system

Current main players

- Windows
- Mac OS
- Linux
- (Unix)



- (Android & iOS on smartphones/tablets)

Linux

- Open-source OS, since 1991
  → free to use, copy, modify but not to sell
  → multiple distributions and flavours
  → supported by a large community
- On PC:
  - now (almost) as easy to use as a Win/Mac with simple GUI
  - typically runs open-source software: Open Office, Gimp,…
  - usually more secured than Windows/Mac
- On servers & clusters
  - Standard OS → need to know command line

Mac OS vs Windows

Mac OS

- 1st version in 1984
- Since 2001, based on a Unix kernel
- Proprietary to Apple, i.e. closed
- With GUI *and* command line
- 2nd most common OS on PC's.
- Usually more secure than Windows OS but limited to proprietary (and €€€) hardware…

Windows

- 1st version in 1985
- Originally graphical operating system shell for MS-DOS
- Proprietary to Microsoft, i.e. closed & €€€
- Other MS software, like Office, are €€€
- Most common OS on PC's
- More exposed to security issues but runs one all sorts of hardware built

All OS's in one computer

Use "virtual machines" (VM) to execute

- an entire OS, with applications, on a virtual hardware ("**system VM**")
- a program in a platform-independent environment ("**process VM**")

on the same physical machine, i.e. original hardware and OS.

→ easy to create, copy, kill, relaunch, distribute,...

For example:

- System VM with 'VirtualBox'
- Process VM with 'Docker' or 'Singularity'

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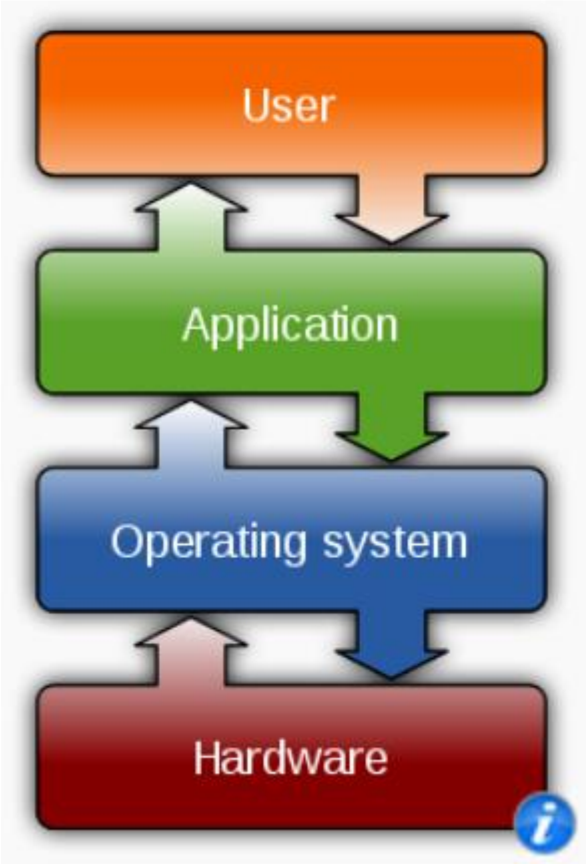
- **Programming languages**



Some wisdom…

"*Programming: when the ideas turn into the real things.*"

- Maciej Kaczmarek

"*The most important single aspect of software development is to be clear about what you are trying to build.*"

- Bjarne Stroustrup

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Classic ones for scientific computing

- C/C++
- Java
- Python
- R
- Perl
- Matlab/Octave
- Julia

NOTE: There exist 1000’ of them!!!

Low vs. high level of programing

- closer to hardware vs. relying on intermediate software layer
- more complicated vs. easier code writing
- tedious vs. more abstract
- faster and efficient vs. usually a bit less so

A “compiler” or “interpreter” translates code to ‘machine code’ to create an executable program or execute it.

High level program example

The perfect Vanilla Cake:

1. *Preheat oven to 350º F.*
2. *Prepare three 8-inch cake pans by spraying with baking spray or buttering and lightly flouring.*
3. *Combine flour, baking powder, baking soda, and salt in a large bowl. Whisk through to combine. Set aside.*
4. *Cream butter until fluffy and then add sugar. Cream together for about 8 more minutes.*
5. *Add eggs, one at a time, and mix just until combined.*
6. *Add flour mixture and buttermilk, alternately, beginning and ending with flour.*
7. *Add vanilla and mix until thoroughly combined.*
8. *Divide among pans and bake for 25-30 minutes until edges turn loose from pan and toothpick inserted into middle of cake comes out clean.*
9. *Remove from the oven and allow to cool for about 10 minutes.*
10. *Turn out onto wire cooling racks and allow to cool completely.*

Compiled vs. Interpreted language

- Compiler → generate machine code from source code
  - typically lower-level language
  - no cross-platform support for exec code (i.e. need to recompile on specific OS)
- Interpreter → step-by-step executors of source code
  - typically higher-level language
  - easy (at least should be easier) cross-platform
- Both available for most *high-level* language
- Can be a mix of both

Wrapping vs. number crunching

- Wrapping $\rightarrow$ relies on other bits of code
  - typically higher-level language
  - glues and pipelines different operations
- Number crunching $\rightarrow$ does the job on some data
  - typically lower-level language
  - takes in data and parameters to calculate an output
- Both available for most *high-level* language
- Can be a mix of both

C and C++

C

- Started in 1973, standardized in 1989
- Low level language (e.g. memory management)
  $\rightarrow$ very efficient when compiled
- Portable on any hardware and OS

C++

- Based on C with added object-oriented & other programing features
- Started in 1979, standardized since 1998

Java

- High-level general-purpose language (class-based and object-oriented)
- ideally "write once, run anywhere" (WORA)
- applications are typically compiled to bytecode that can run on any “*Java Virtual Machine*” (JVM) regardless of computer architecture
- open-source compiler (GNU GPL)
- fairly stable

Python

- started in 1991, latest version (3.9.7) out in August 2021.
- interpreted high-level programming language for general-purpose programming
- dynamic type system, object-oriented and automatic memory management.
- relies on large and comprehensive standard library.
- interpreters available for many OS's.
- open source with community-based development model
- still evolving: main version (https://fr.wikipedia.org/wiki/Python_(langage)#Historique_des_versions) and libraries

R

- started in 1992, stable since 2000
- open source with community-based development model
- high-level interpreted language, free software environment (GNU GPL)
- mostly used among statisticians and data miners for developing statistical software and data analysis.
- pre-compiled binary versions available for most OS's.
- command line interface, plus graphical front-ends and IDE's ("Integrated Development Environments).

Perl

- started in 1987, v5.32 released in June 2020
- originally general-purpose Unix scripting language to make report processing easier
- Built in C, free software environment (GNU GPL)
- very good at text processing without the arbitrary data-length limits
- high-level, general-purpose, interpreted, dynamic programming languages
- nicknamed the "duct tape": glue language and perceived inelegance

Matlab/Octave

- started in 1984 by MathWorks, based on C and Lapack libraries
- multi-paradigm numerical computing environment, good at matrix manipulations, implementation of algorithms
- can interface with programs written in C, C++, Java, and Python.
- large number of users-contributed (open source) packages
- but proprietary programming language $\rightarrow$ €€€ license
- fairly stable (back compatibility!)
- Octave = free alternative to Matlab but not 100% compatible or as efficient

Julia

- started in 2012, v1.6.3 released in September 2021
- free open-source language, runs on most OS's
- high-level general-purpose dynamic programming language
- originally designed for high-performance numerical analysis and computational science
- allows concurrent, parallel and distributed computing, and direct calling of C and Fortran libraries
- includes efficient libraries for floating-point calculations, linear algebra, random number generation, and regular expression matching.
- other libraries are available from the community

Some wisdom…

"The only way to learn a new programming language is by writing programs in it."

\- Dennis Ritchie

Still

- some algorithm/coding principles remain the same across languages
- pick the language of your community/appropriate for your data
- do not reinvent the wheel

https://twitter.com/CodeWisdom

Some further wisdom…

"The good news about computers is that they do what you tell them to do.

The bad news is that they do what you tell them to do."

- Ted Nelson

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