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Introduction to computer science:

historical perspective, computer structure, operating systems & languages

Doctoral School for Health Sciences

FREEDOM TO RESEARCH

Christophe Phillips, Ir Ph.D.

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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- Computer structure
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Historical perspective

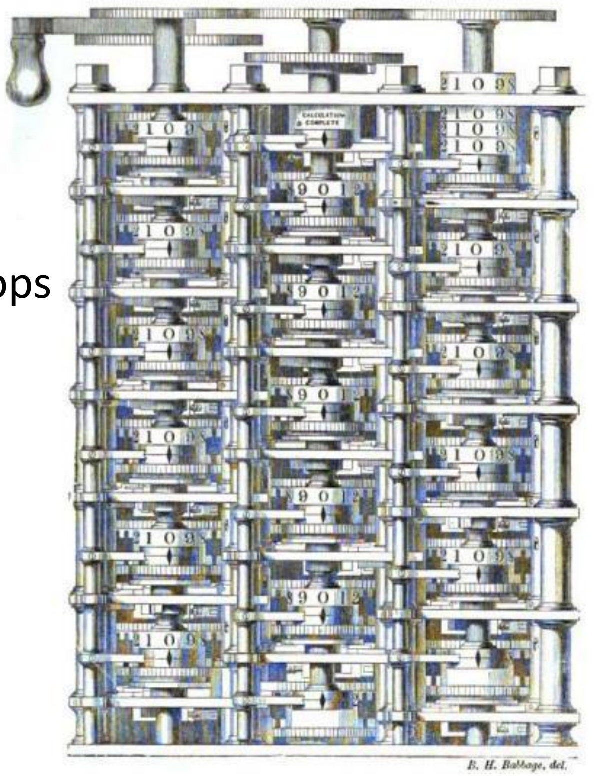
Computer science did NOT suddenly appear during World War II out of a genius mind.

Three parallel streams:

- Calculation instruments, from abacus to Pascal's mechanical calculator
- Mathematical logic, from al-Khwarizmi (VIIIth century) to Alan Turing (XXth century)
- Automats, from antiquity (e.g. Hero of Alexandria's 1st 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.

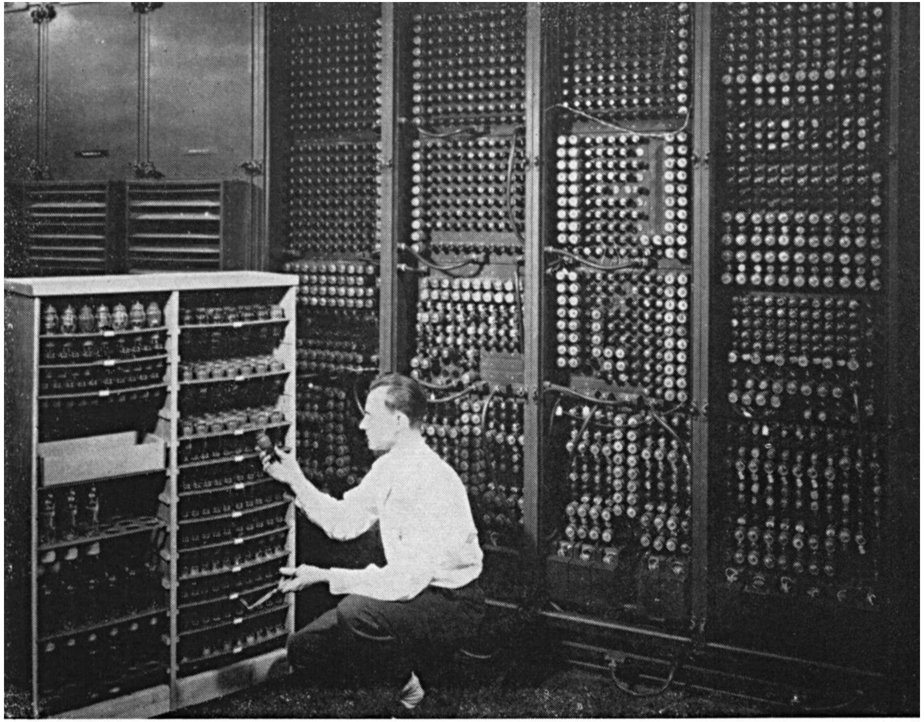


Historical perspective

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

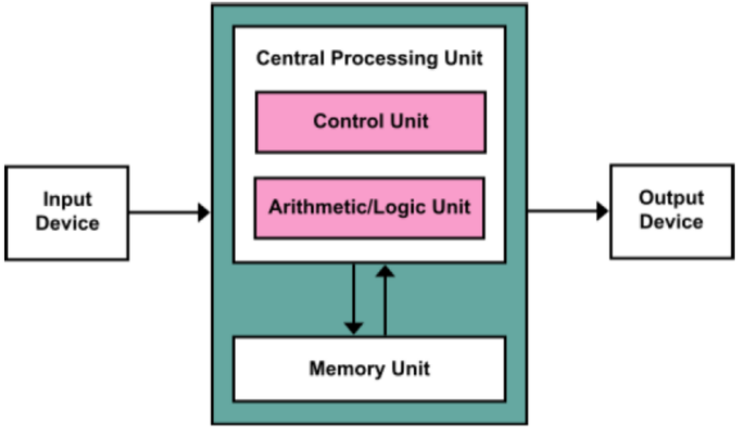
Programs hard coded into the machines with 10000's of switches and plugs!

(…and bugs were real!)



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

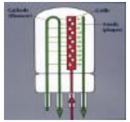
Von Neumann architecture



- 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 program instructions and data in read-write, "random-access memory" (RAM)!

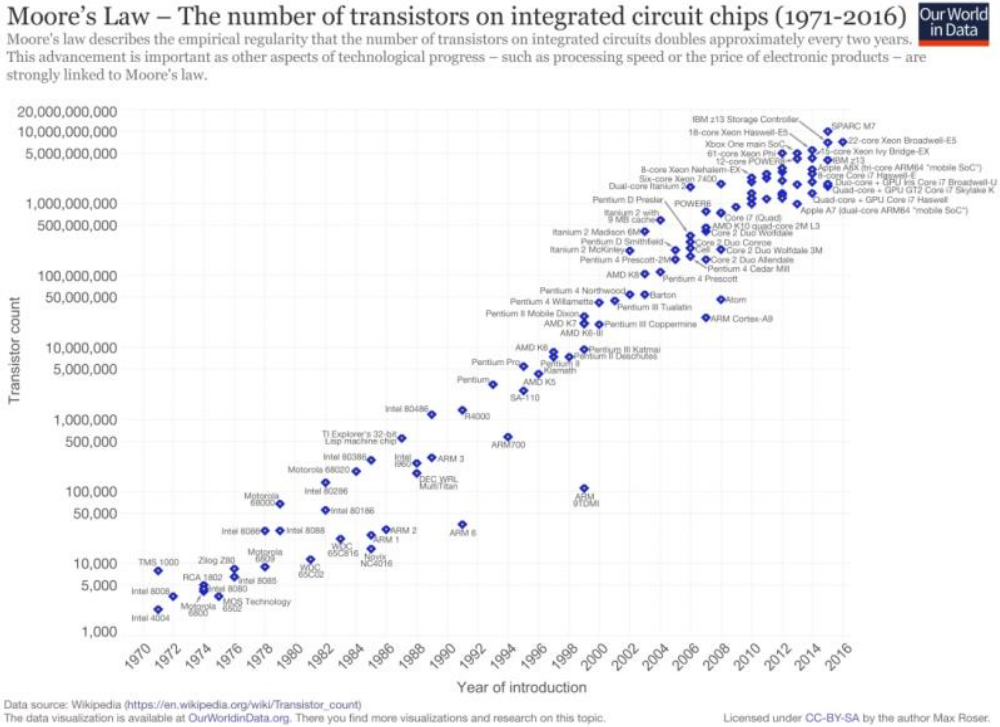
Hardware innovations



- 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…)

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

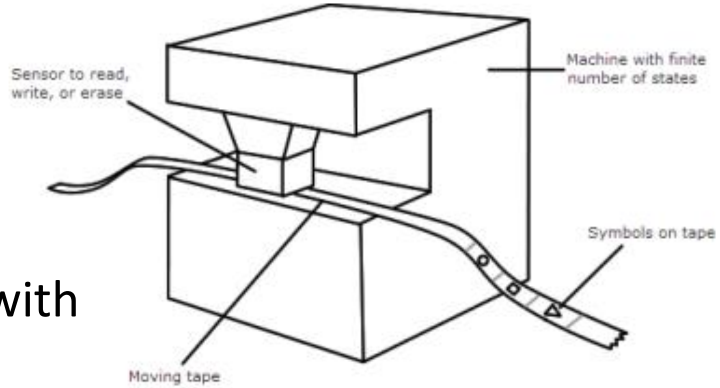
Definition:

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 machine 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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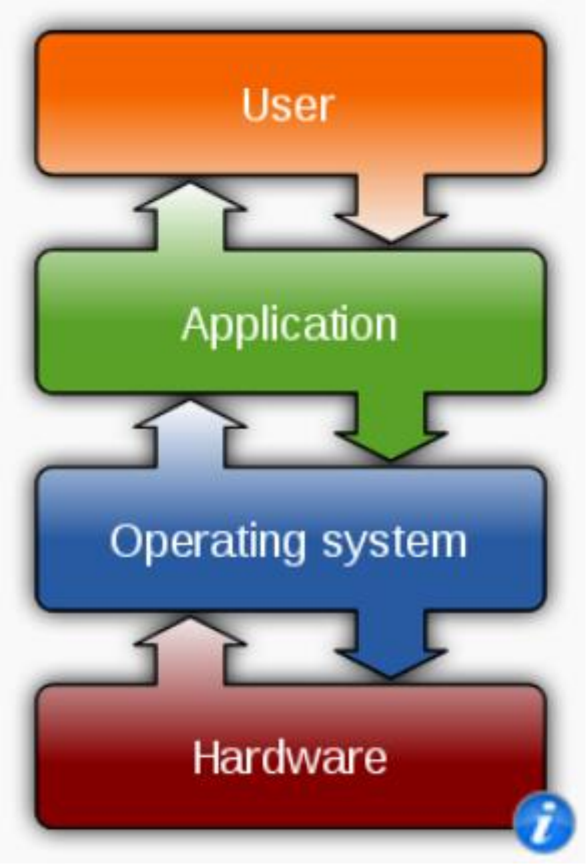
Program

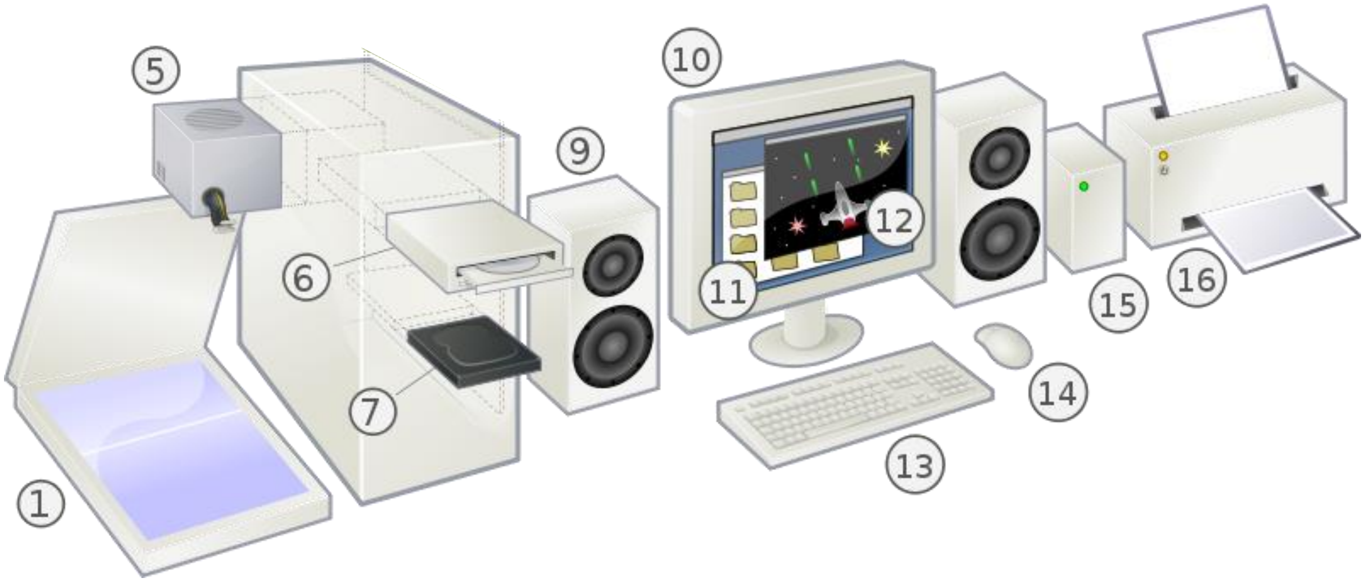
- Historical perspective
- Computer structure
- Operating systems
- Languages



Outside the “motherboard”

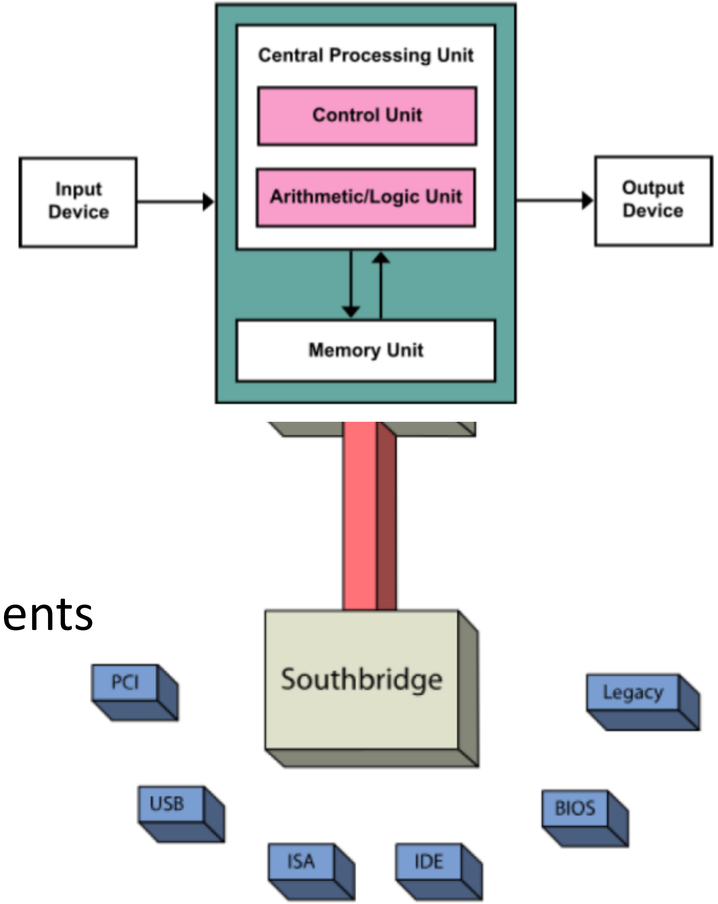
Peripherals:

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 (internal) 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”



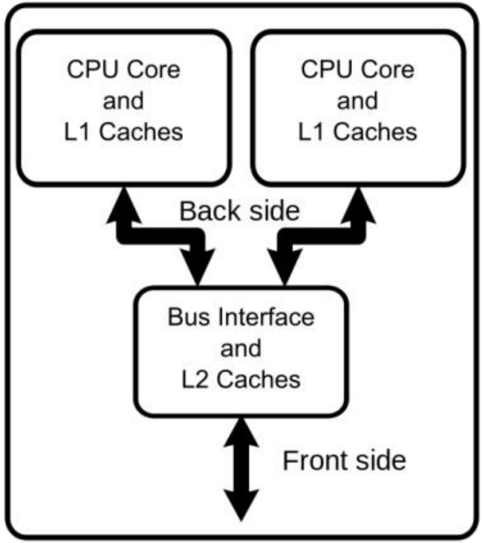
Different types of memory

- RAM,
  - fast but not persistent → used by microprocessor (data & operations)
  - limited to a few GB
- Hard drive
  - slower but persistent → used to store data, code, OS
  - up to several TB
- Cache
  - inside the CPU → 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!)

Faster & more power, cluster

High performance computing (HPC) with a cluster

- set of connected computers with multi-core processor, split into “nodes”.
- parallelization of the processing, at low or high level
- shared resources

Caveats

- shared resources
- specific code & no GUI
- data & results transfer and management

Consortium des Équipements de Calcul Intensif

CECI, available & accessible at ULiege:

Cluster	Host	CPU type	CPU count*	RAM/node	Network	Filesystem**	Accelerator	Max time	Preferred jobs***
NIC5	ULiège	Rome 2.9 GHz	4672 (73 x 64)	256 GB..1 TB	HDR Ib	BeeGFS 520 TB	None	2 days	MPI
Hercules2	UNamur	Naples 2 GHz SandyBridge 2.20 GHz	1024 (30 x 32 + 2 x 64) 512 (32 x 16)	64 GB..2 TB	10 GbE	NFS 20 TB	None	15 days	serial / SMP
Dragon2	UMons	SkyLake 2.60 GHz	592 (17 x 32 + 2 x 24)	192..384 GB	10 GbE	RAID0 3.3 TB	4x Volta V100	21 days	serial / SMP
Lemaitre3	UCL	SkyLake 2.3 GHz Haswell 2.6 GHz	1872 (78 x 24) 112 (4 x 28)	95 GB 64 GB	Omnipath	BeeGFS 440 TB	None	2 days 6 hours	MPI
Dragon1	UMons	SandyBridge 2.60 GHz	416 (26 x 16) 32 (2x16)	128 GB	GbE	RAID0 1.1 TB	4x Tesla C2075, 4x Tesla Kepler K20m	41 days	serial / SMP

http://www.ceci-hpc.be/

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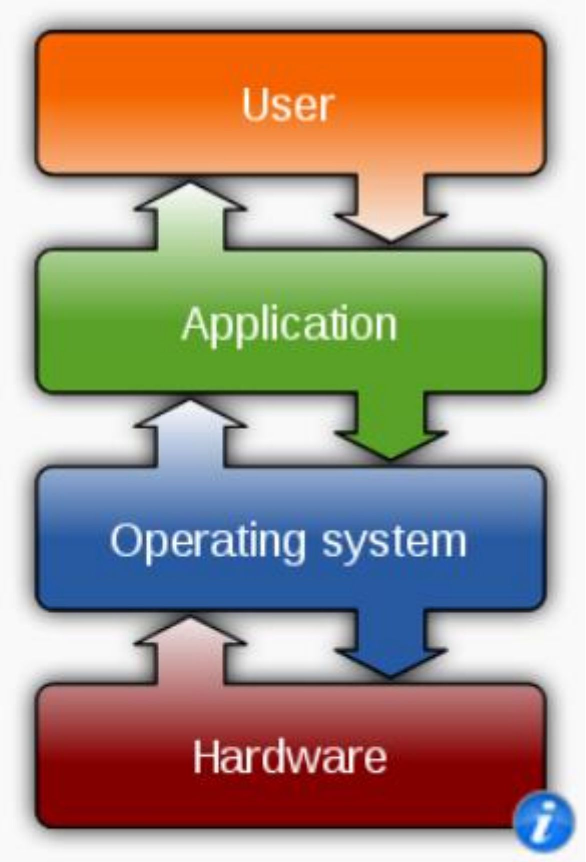
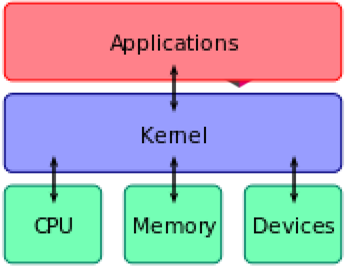
Program

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



OS definition



An “**operating system**” (OS)
= first program launched at start up!
= system fundamental software to

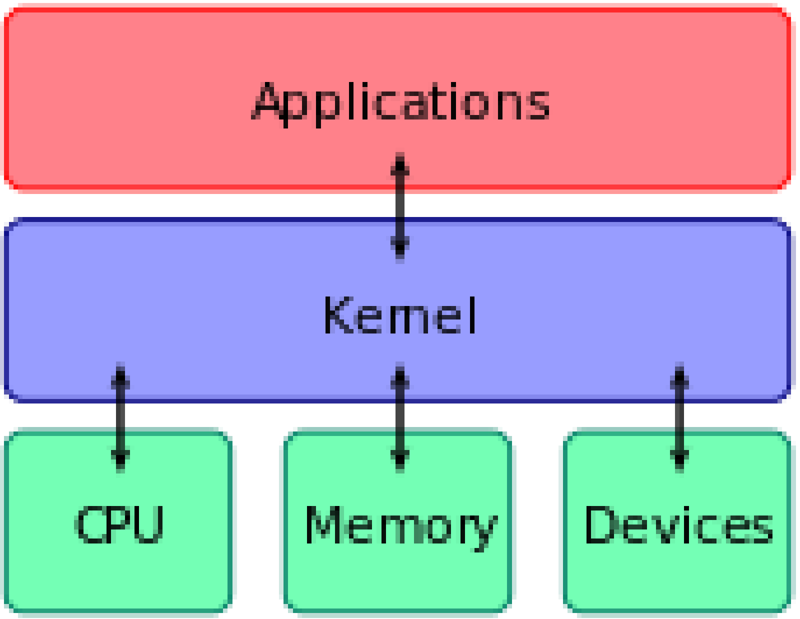
- manage computer hardware and software resources,
- protects system’s integrity against incorrect apps, and
- provide common services for computer programs:

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

- 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…

- 1st version in 1985
- Originally graphical operating system shell for MS-DOS. Now most common OS on PC's
- Proprietary to Microsoft, i.e. closed & €€€
- Other MS software, like Office, are €€€
- 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.

$\rightarrow$ easy to create, copy, kill, relaunch, distribute,...

For example:

- System VM with 'VirtualBox'
- Process VM with 'Docker' or 'Singularity', aka "container"

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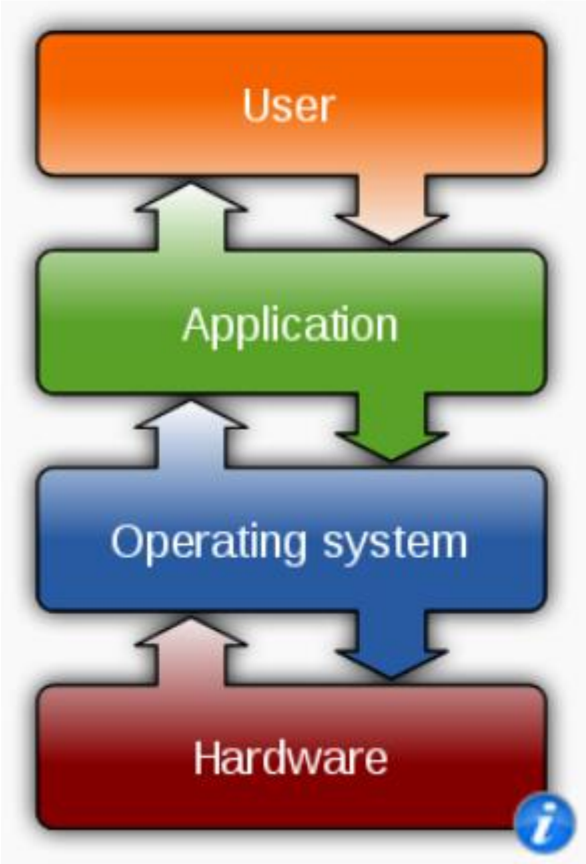

Some wisdom…

"*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

- …
- Fortran
- 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

FORTRAN

- appeared in 1957, developed by IBM
- latest release “Fortran 2023” in November 2023
- designed for computationally intensive scientific and engineering applications
- low level language (but dynamic memory allocation)
  $\longrightarrow$ very efficient when compiled (LAPACK is written in Fortran 90!!)
- portable on any hardware and OS
- popular language for “high-performance computing” and is used for programs that benchmark and rank the world's fastest supercomputers

C and C++

C

- started in 1973, ISO standardized in 1989, latest release in October 2024
- 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 programming* (OOP) & other features
- started in 1979, ISO standardized since 1998, latest (stable) release in October 2024

Object-oriented programming (OOP)

Programming paradigm based on the concept of **objects**.

"An object is a data structure or abstract data type containing fields (state variables containing data) and methods (subroutines or procedures defining the object's behavior in code)."

Example:

- a graphics program → objects such as "circle", "square", and "menu";
- online shopping system → objects such as "shopping cart", "customer", and "product".

➔ Data "abstraction" and "encapsulation" = external code does not know about internal working of an object.

Java

- appeared in May 1995, latest release (Java SE 23 (LTS)) in September 2024
- developed by *Oracle Corp*
- 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 (3.13.1) out in December 2024 .
- 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 versions (https://fr.wikipedia.org/wiki/Python_(langage)#Historique_des_versions) and libraries

R

- started in 1992, stable since 2000, latest release (v4.4.2) in October 2024
- 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, v5.40 released in June 2024
- 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*” because “glue language and perceived inelegance”

Matlab/Octave

- started in 1984 by MathWorks, based on C and Lapack libraries (written in Fortran)
- multi-paradigm numerical computing environment, good at matrix manipulations, implementation of algorithms
- can interface with programs written in C, C++, Java, Julia and Python.
- large number of users-contributed (open source) packages
- but proprietary programming language $\rightarrow$ €€ license
- yearly releases with new features but fairly stable (back compatibility!)
- Octave = free alternative to Matlab but not 100% compatible or as efficient latest release in March 2024

Julia

- started in 2012, v1.11.3 released in January 2025
- 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

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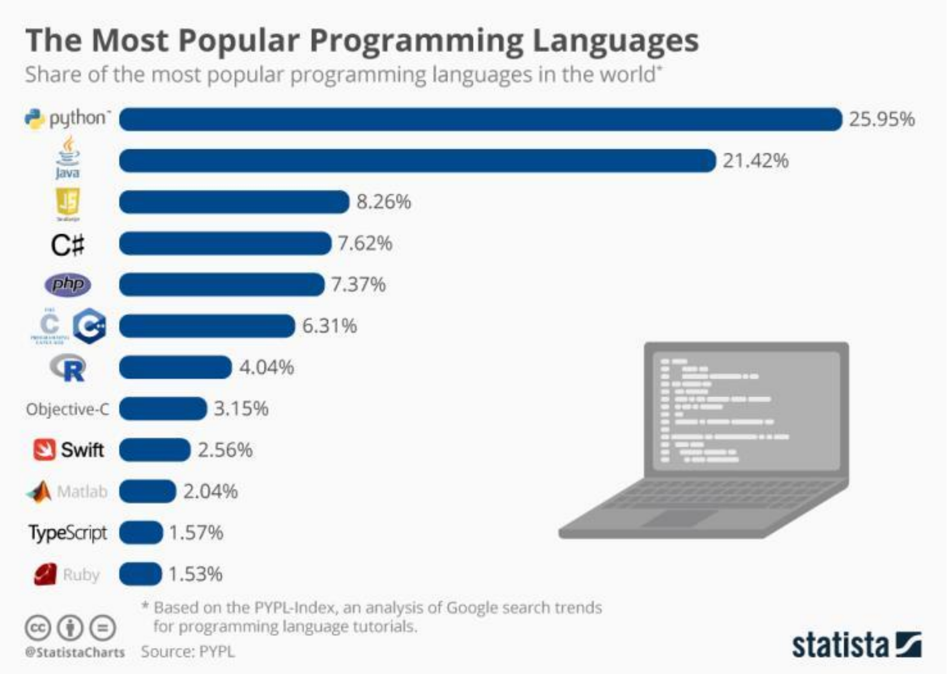
Programming languages in industry…



Size of programming language communities in Q3 2021

Active software developers, globally, in millions (n=12,506)

		Most popular in	Least popular in
Javascript*	16.4 M	Web, backend	DS/ML, embedded
Python	11.3 M	DS/ML, IoT apps	Mobile, AR/VR
Java	9.6 M	Mobile, desktop	DS/ML, web
C/C++	7.5 M	Embedded, IoT apps	Web, mobile
PHP	7.3 M	Web, backend	DS/ML, mobile
C#	7.1 M	AR/VR, desktop, games	DS/ML, mobile
Visual development tools	3.6 M	Desktop, AR/VR	Cloud, web
Kotlin	2.9 M	Mobile, AR/VR	DS/ML, desktop
Swift	2.5 M	Mobile, AR/VR	Backend, desktop
Go	2.0 M	Backend, apps for 3rd-party ecosystems	Games, web
Dart	1.4 M	Mobile	Web
Objective C	1.4 M	AR/VR	Desktop, games
Ruby	1.4 M	IoT, backend	DS/ML, web
Rust	1.1 M	AR/VR, embedded	Mobile, web
Lua	0.8 M	AR/VR, IoT, games	Mobile, desktop

/DATA

(*) JavaScript includes CoffeeScript and TypeScript

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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