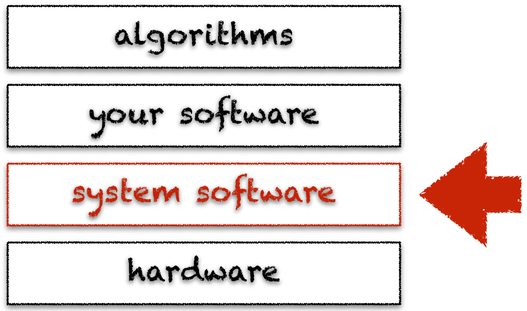
system software

learning objectives



- understand the role of an operating system
- understand the role of interpreters and compilers
- understand the role of runtime systems & libraries

what's system software?

application software consists in programs that
help to solve a particular computing problem,
e.g., write documents, browse the web, etc.

system software consists in programs that sit
between application software and the hardware,
providing common services to application software

example of system software

- operating systems, game engines
- virtual machines and interpreters
- language runtimes, standard libraries

bits of history

1940s
1950s ◆ no system software

1960s ◆ batch systems

the
waiting era

1970s ◆ multi-user & time-sharing

the
sharing era

1980s ◆ personal desktop computers

the
personal era

1990s ◆ distributed systems

the
communication era

2000s ◆ mobile systems

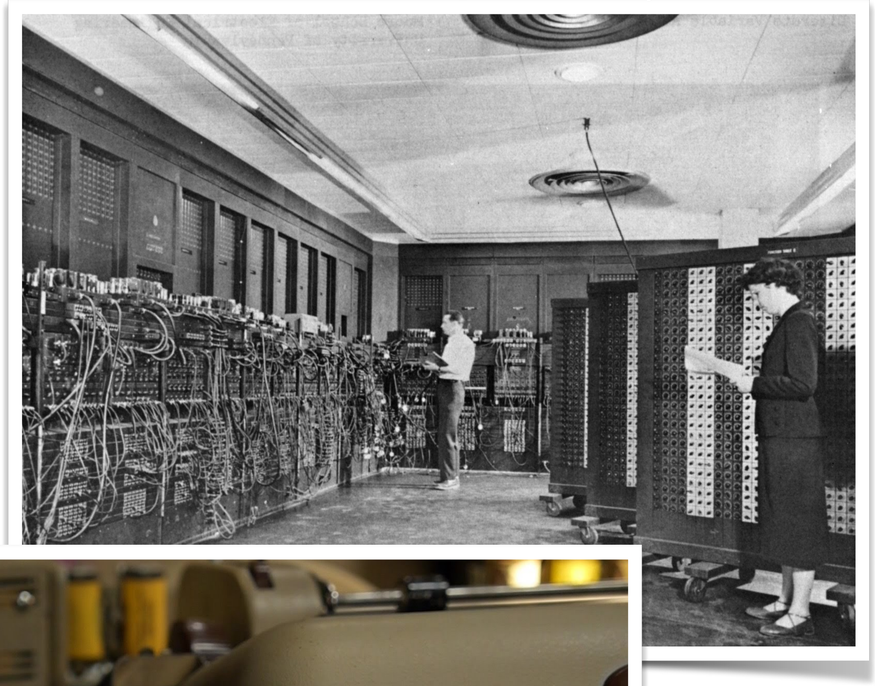
2010s ◆ ubiquitous systems

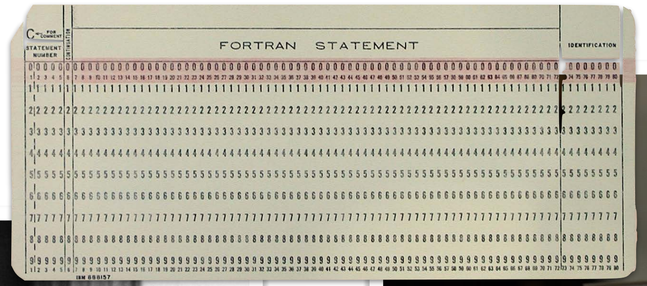
the digital
transformation era

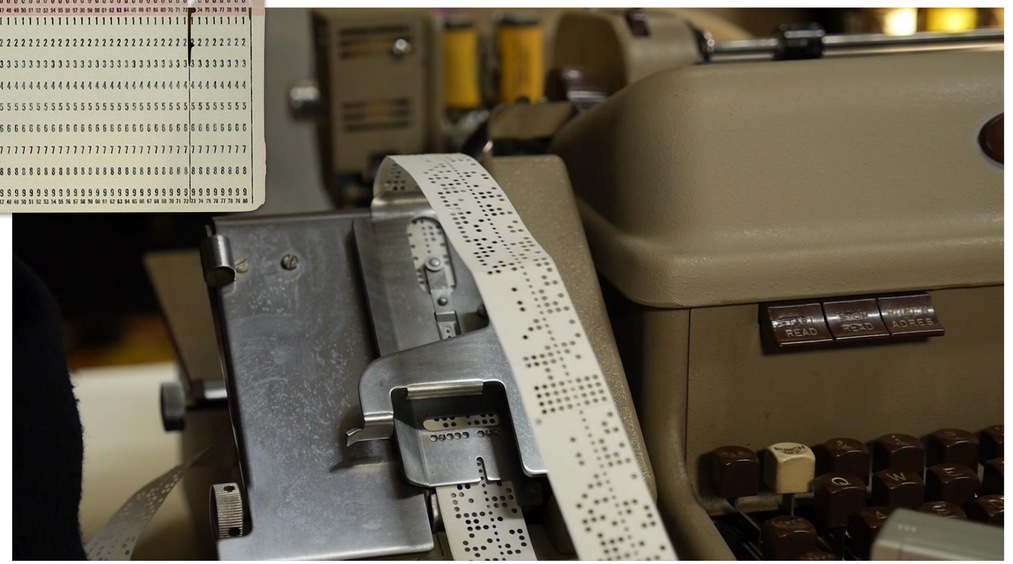
no systems software

- 1940s: programming based on dials & switches
  - 1950s: single user, punched cards, paper tape

ENIAC: 30 tons, 200 kilowatts

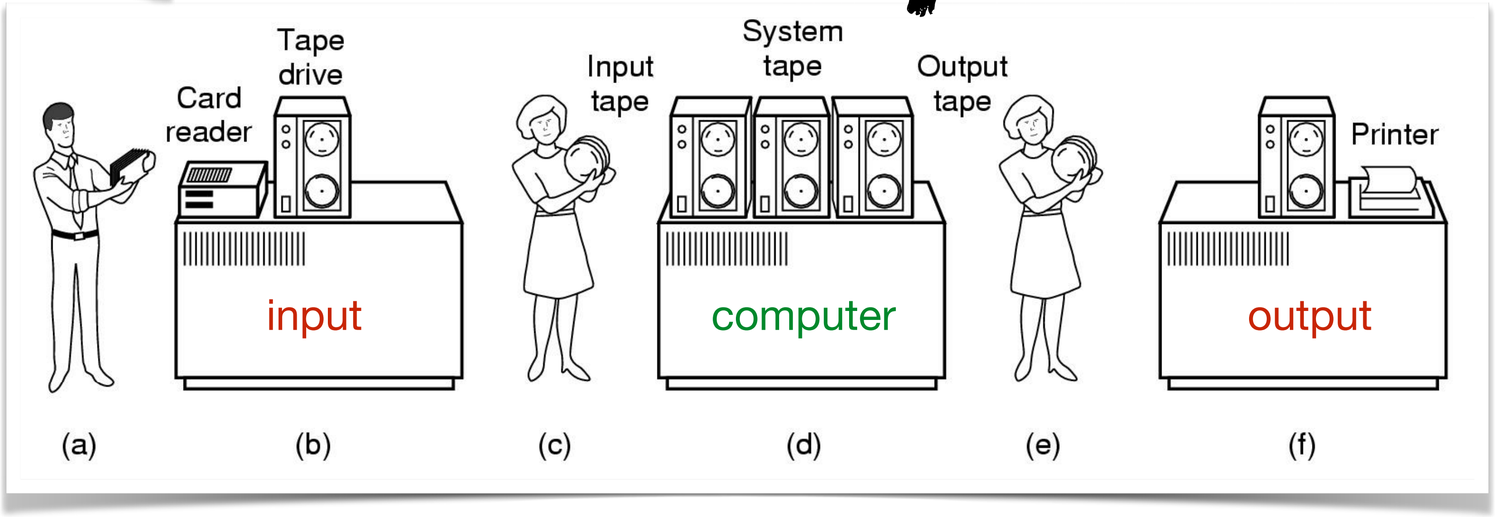






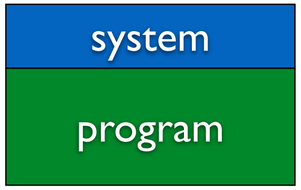
1960s

batch systems

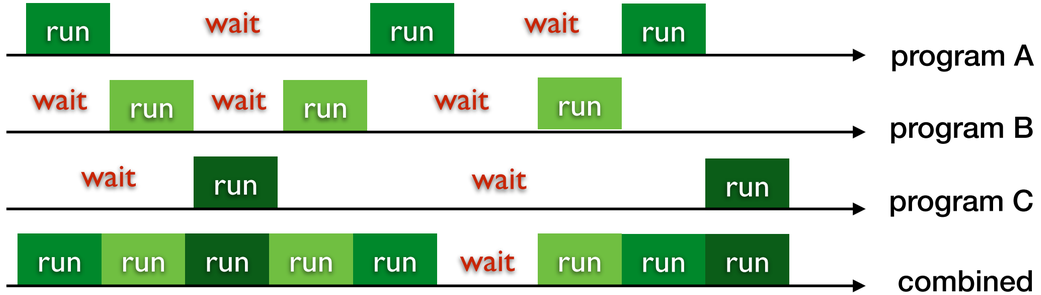


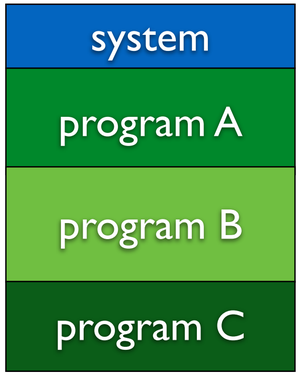
(a) put cards into reader
(b) read cards to tape
(c) put input tape on computer
(d) perform the computation
(e) put output tape on printer
(f) print output tape on paper

- first uni-programmed batch systems



- then multi-programmed batch systems





1970s multi-user & time-sharing

from Multics...

...to Unix

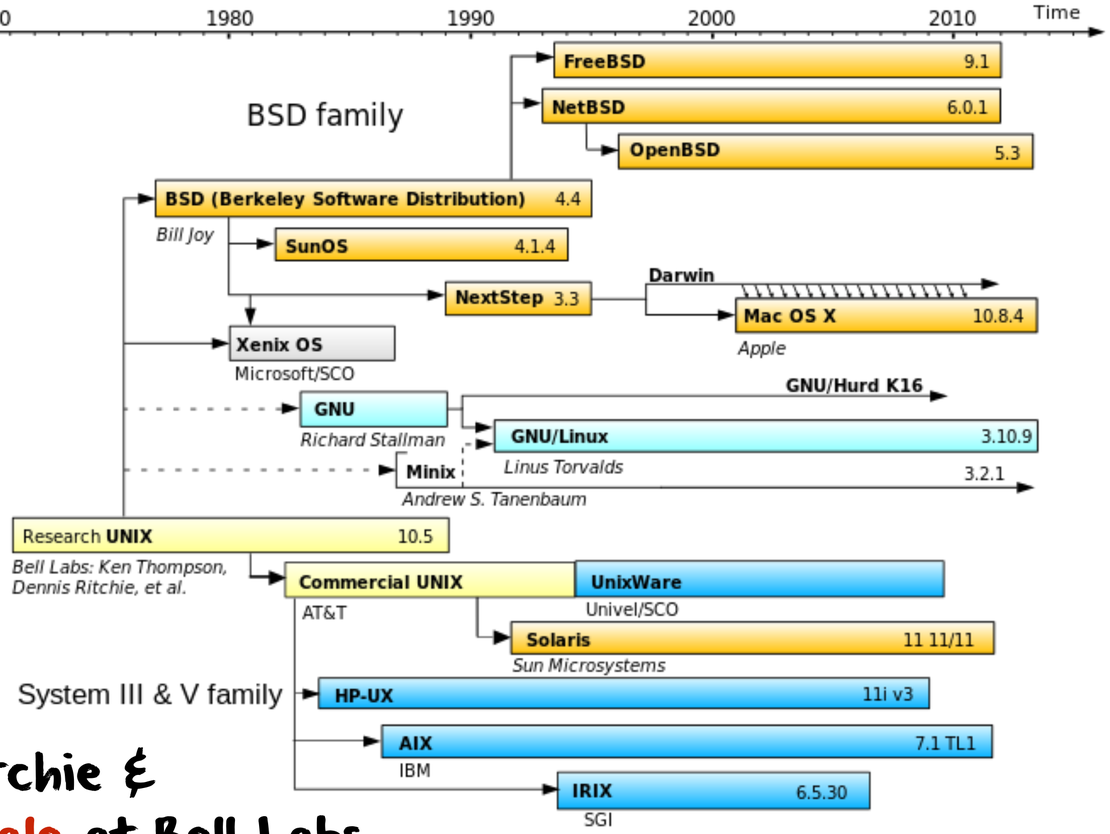
- 1960s: disasters... but great learning & innovations
  - OS/360: years behind schedule, shipped with 1000 known bugs
  - Multics: started in 1963, working in 1969, far too complex
- 1970s: finally mastering complexity thanks to:
  - higher level structured languages (Algol, C, Pascal, etc.)
  - portable operating systems code (C was invented for that)
  - stacking layers (kernel, compilers, libraries, etc.)

solaris

Unix

hp UX

AIX



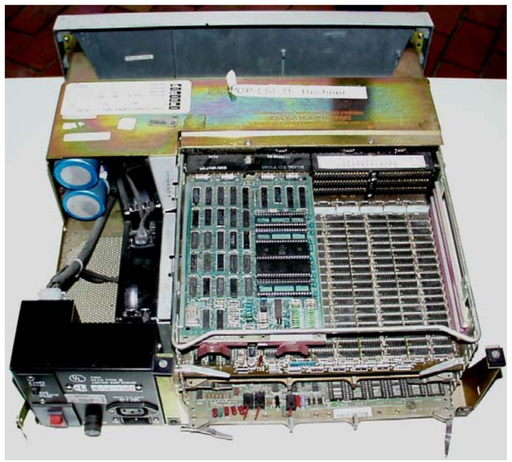
- after the Multics "disaster", Ken Thompson, Dennis Ritchie & others decided to redo the work on a much smaller scale at Bell Labs
  - in 1972, Unix was rewritten from assembly language to C programming language, resulting in the first portable operating system
    - in 1975, Ken Thompson was on sabbatical at Berkeley and worked with Bill Joy, then a graduate student, which eventually lead to BSD Unix
      - in 1980, the DARPA project chose BSD Unix as basis for DARPANet
        - in 1982, Bill Joy joined Sun Microsystems six months after its creation as full co-founder and extended BSD Unix to make it a networked operating system

how did we get there?

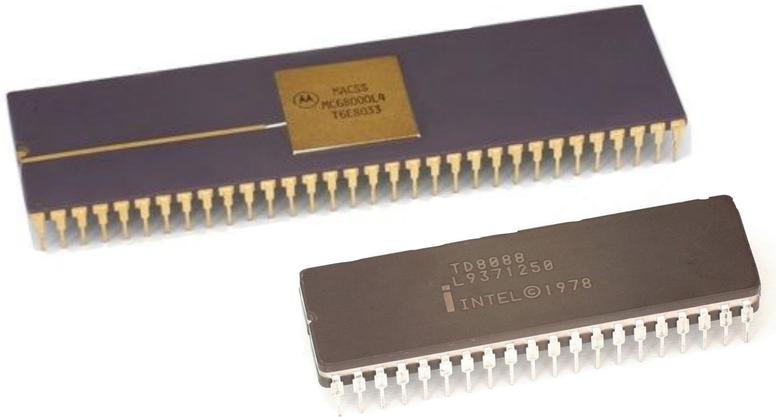
the invention of the microprocessor

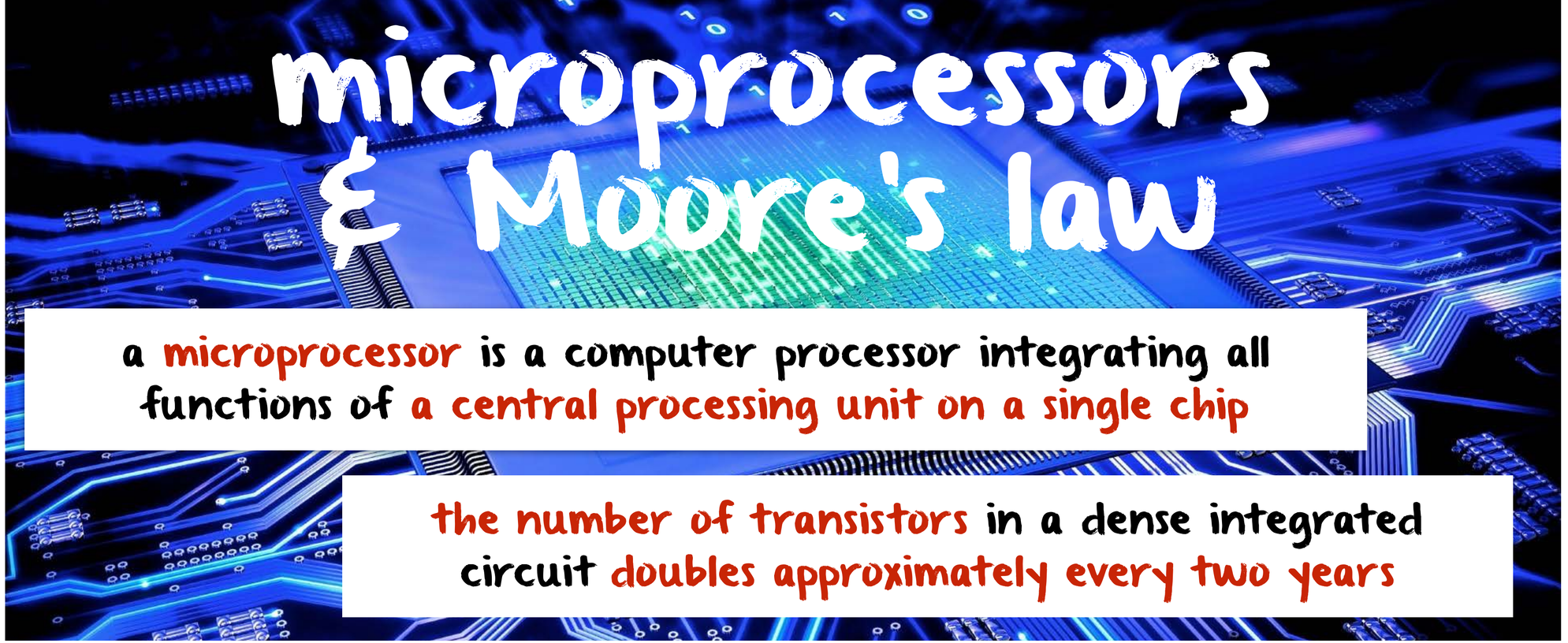
IBM System/360

DEC PDP-11



DEC PDP-11 Processor





microprocessors & Moore's law

a microprocessor is a computer processor integrating all functions of a central processing unit on a single chip

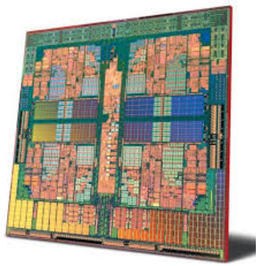
the number of transistors in a dense integrated circuit doubles approximately every two years

- this is unique across all engineering fields
  - transportation increased speed from 20 km/h (horse) to 2'000 km/h (concorde) in 200 years but the computer industry has been doing this every decade for the past 60 years
    - the advent of the microprocessor triggered the decline of mainframes and led to the personal computer revolution

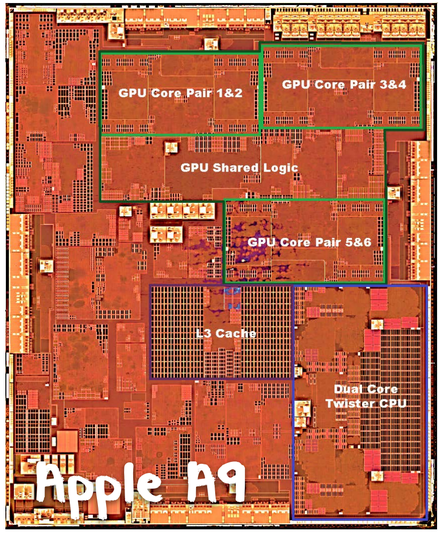
writing system software is about mastering exponential complexity

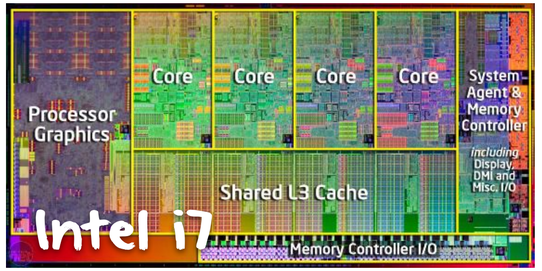
As long as there were no machines, programming was no problem at all; when we had a few weak computers, programming became a mild problem and now that we have gigantic computers, programming has become an equally gigantic problem. In this sense the electronic industry has not solved a single problem, it has only created them - it has created the problem of using its products.

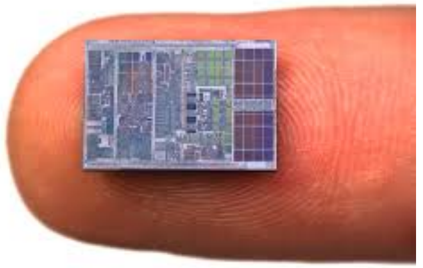
Edgster Dijkstra, The Humble Programmer. Communication of the ACM, vol. 15, no. 10. October 1972. Turing Award Lecture.



the industry is now going multicore







acceleration

1980 1990 2000 2010

1980s: one man, one computer

- workstation, personal computers
- graphical user interfaces

1990s: the network is the computer

- the Internet accessible to all
- distributed operating systems

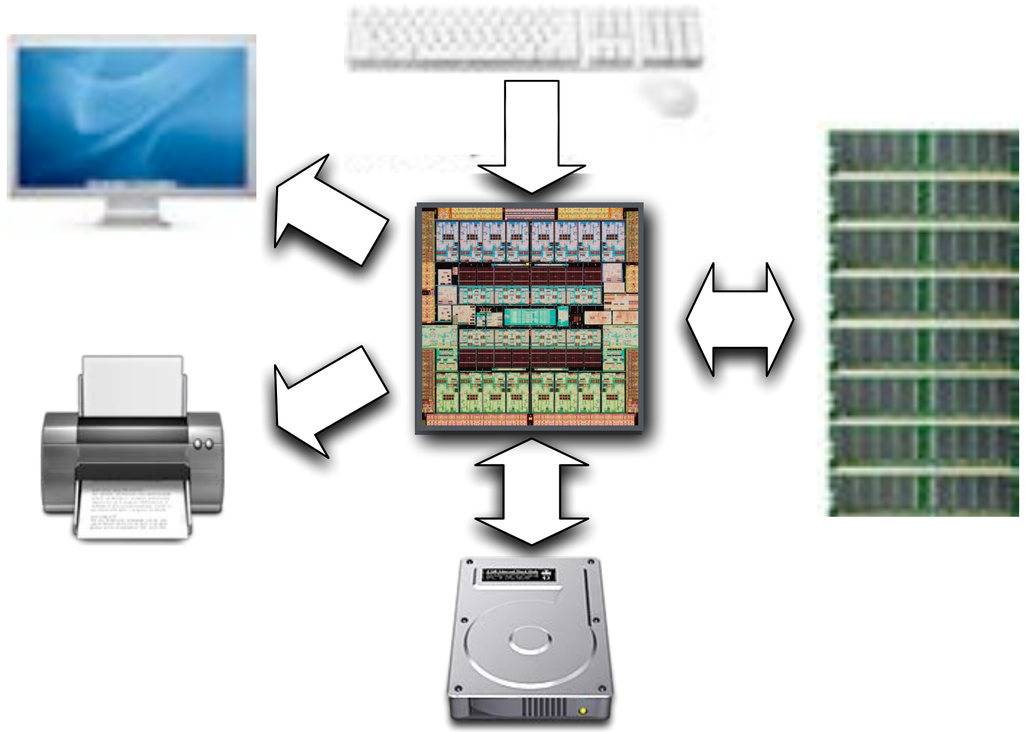
2000s: my phone is my computer

- smartphones & tablets as computers
- generalization of wireless networks

2010s: everything is a computer

- smart objects & the Internet of things
- personal networks connected to the cloud

operating system

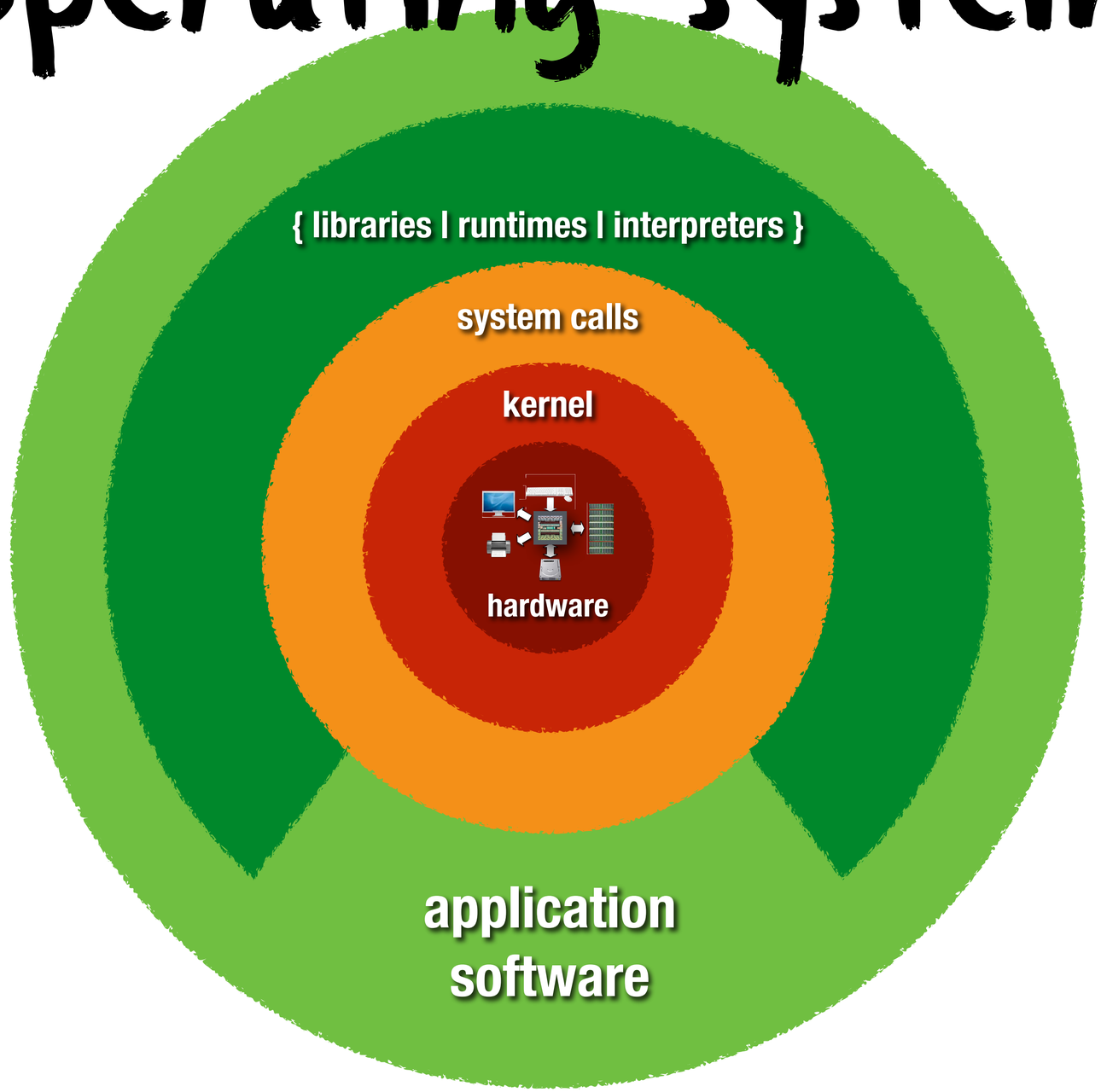


controls the access to hardware resources

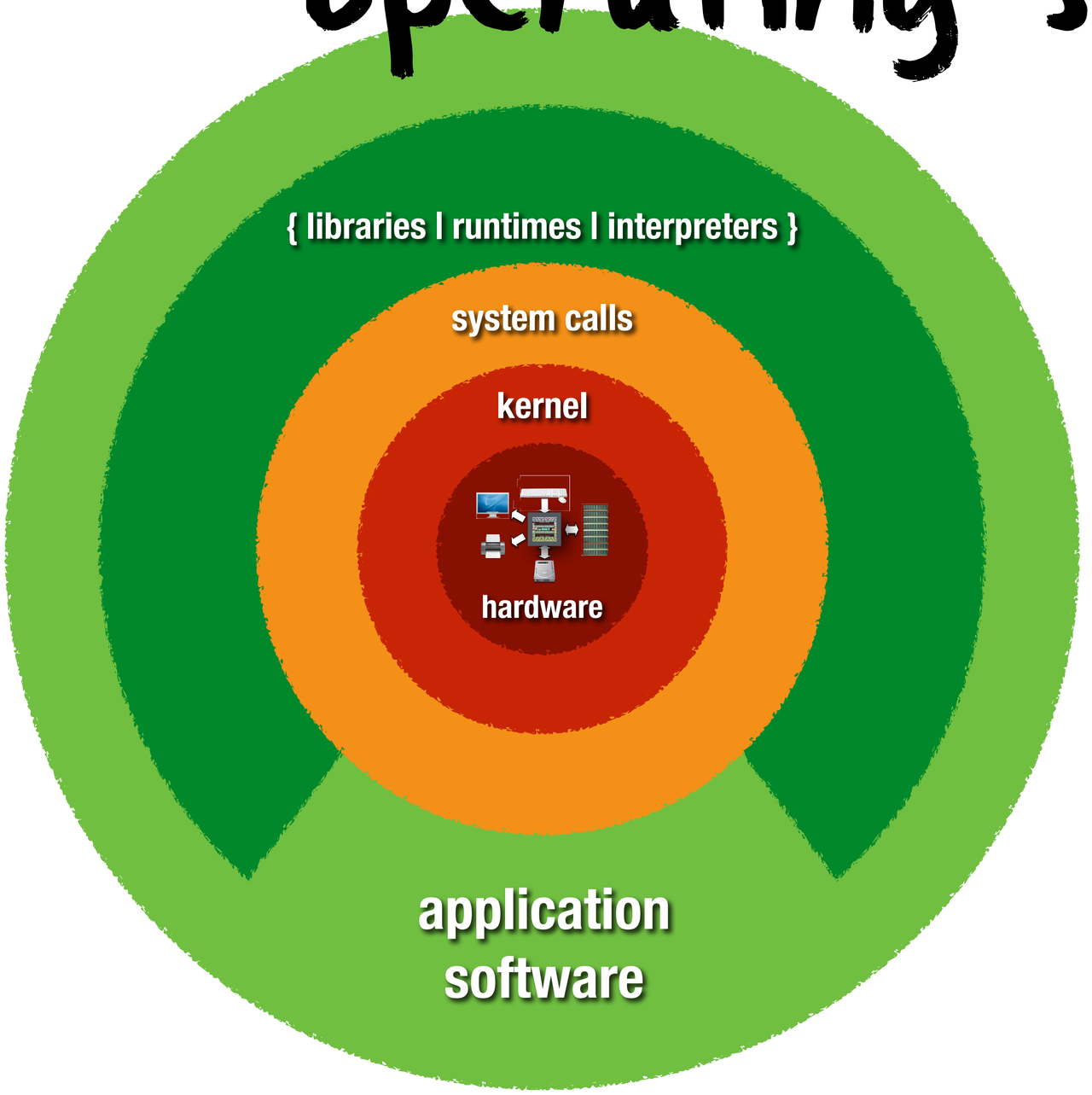
(cpu, memory, input/output devices, etc.) and acts as

an interface with application software

operating system

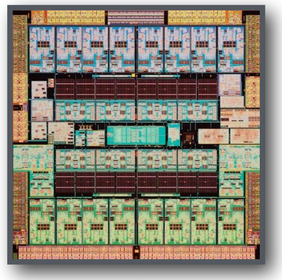


operating system

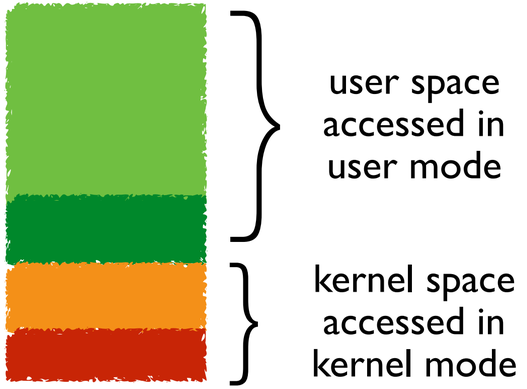


processor modes

- kernel mode (system)
- user mode (application)



memory protection



operating system

resource management

- **cpu**: process management
  - **memory**: memory management
    - **input/output**: i/O management
      - keyboard, mouse, display
      - touch screen, haptic interface, network
      - printer, audio device, connectors (usb, dvi, etc.)
      - compass, accelerometer, global positioning system
      - etc...
    - **storage**: storage and file management

	reality (physical resources)	abstraction (virtual resources)
CPU	***n parallel cores***	***m concurrent threads***, *with* ***m*** $\gg$ ***n***
memory	***subset of*** 2^k ***addressable memory*** *on a* ***k*** *bits machine, e.g., for* ***k = 64***, *this is typically* ***8 to 32 gigabytes***	***full*** 2^k ***addressable memory*** *for* ***k = 64***, *this is* ***16 exabytes*** $\cong$ ***16*** $\times$ 10^6 ***terabytes*** $\cong$ ***16*** $\times$ 10^9 ***gigabytes***
	in addition, each thread can access the full 2^k ***addressable memory*** *as if it was for its exclusive use*	
storage	*hard disk drive (hdd), solid state drive (ssd), usb keys, etc...*	*file system offering persistency*
network	***i network interfaces***, *e.g., wifi, ethernet*	***j network connections***, *with with* ***j*** $\gg$ ***i***

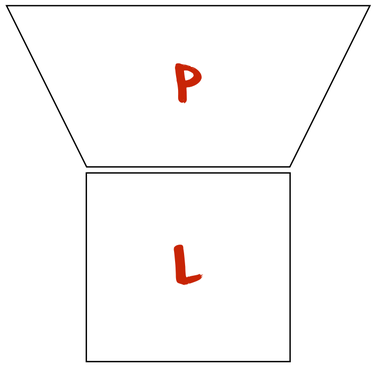
executions and interpreters

concept

program P

written in

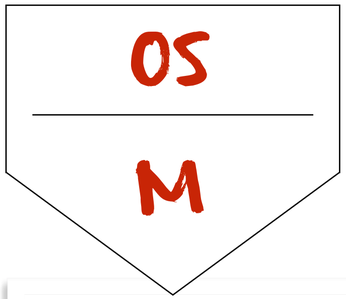
language L



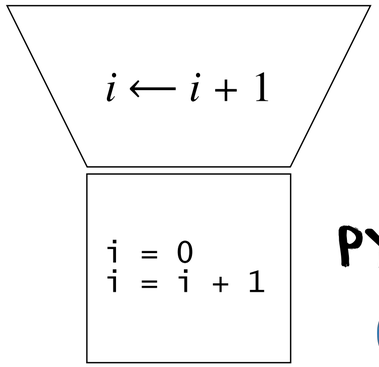
operating system OS

controlling machine

executing language M



examples

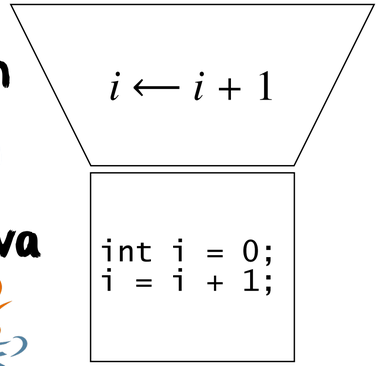


an addition

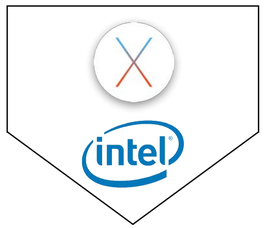
written in

python

java



Samsung S7
running Android
on ARM



MacBook Pro
running OS X
on Intel

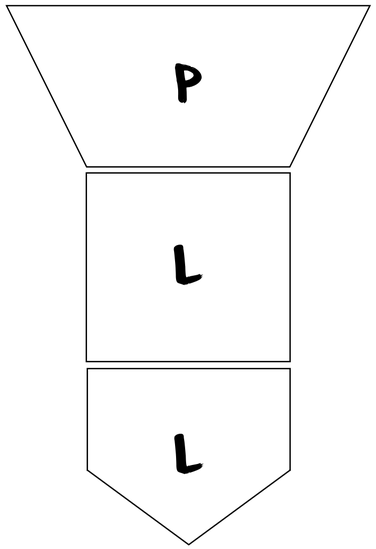
Oracle Server
running Solaris
on SPARC

machine language M ⇔ instruction set ⇔ byte code

executions and interpreters

concept

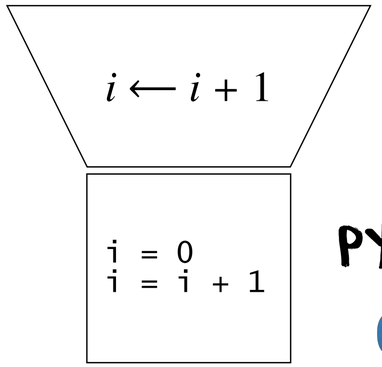
program P
written in
language L
running on
machine L



program language must match machine language

we forget about the operating system for now

examples



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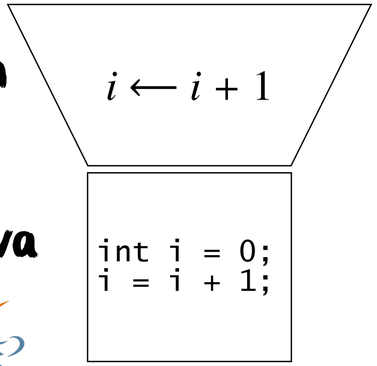

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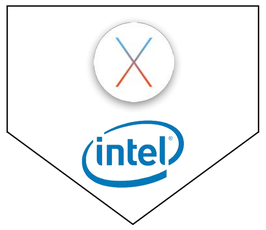

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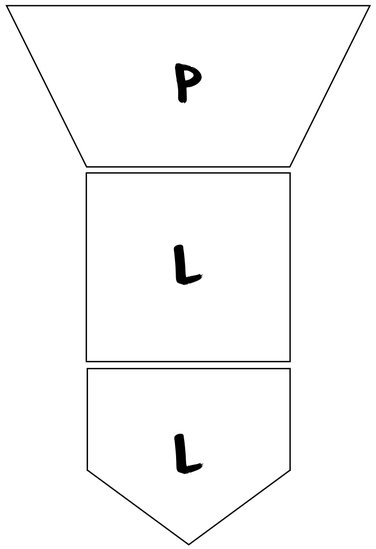

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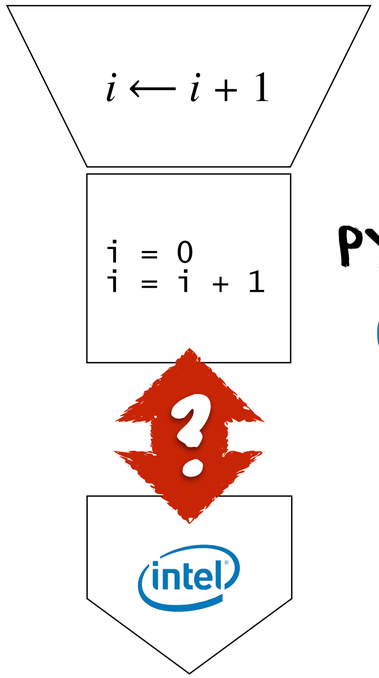
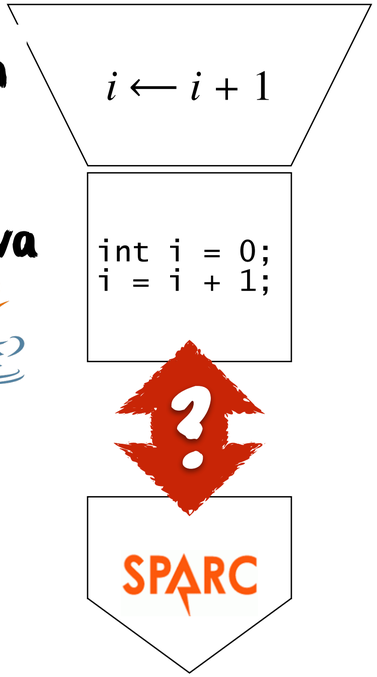
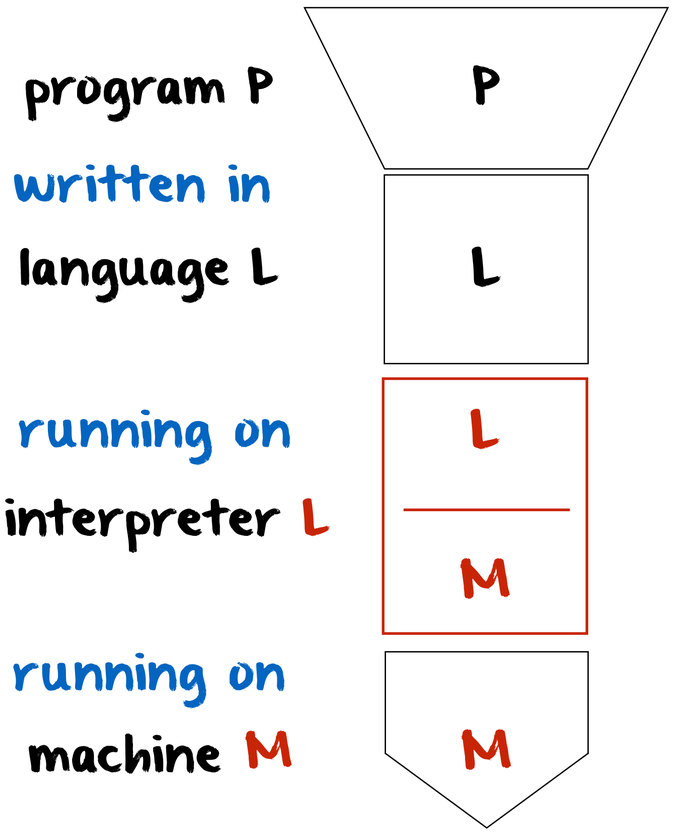




problem!

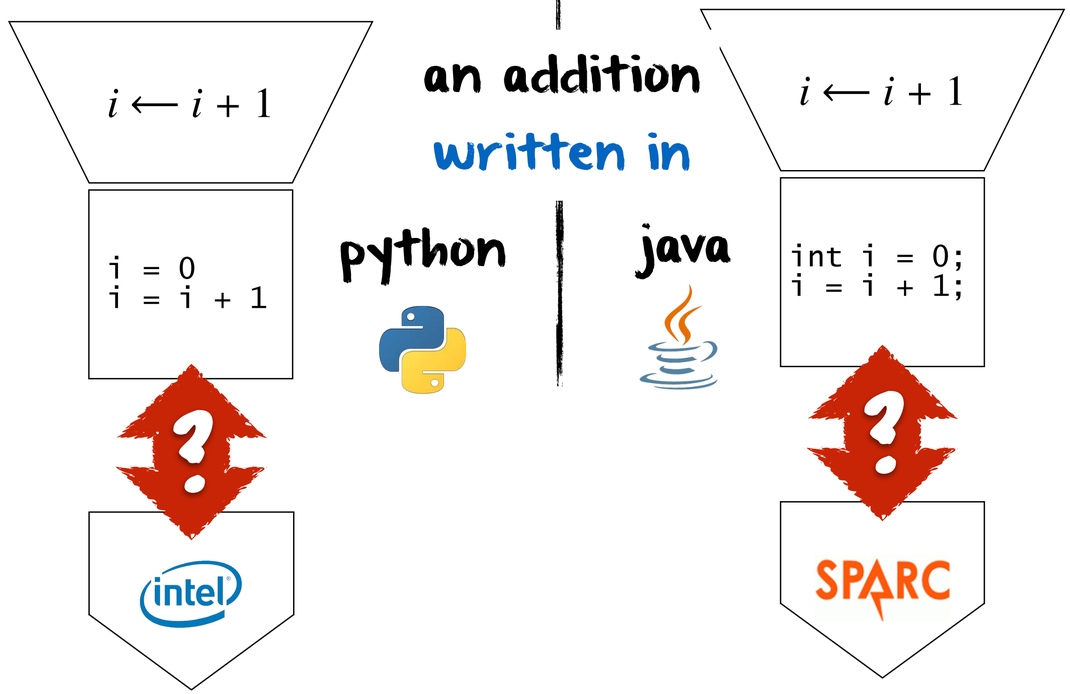
executions and interpreters

concept



an interpreter dynamically translates language L into language M

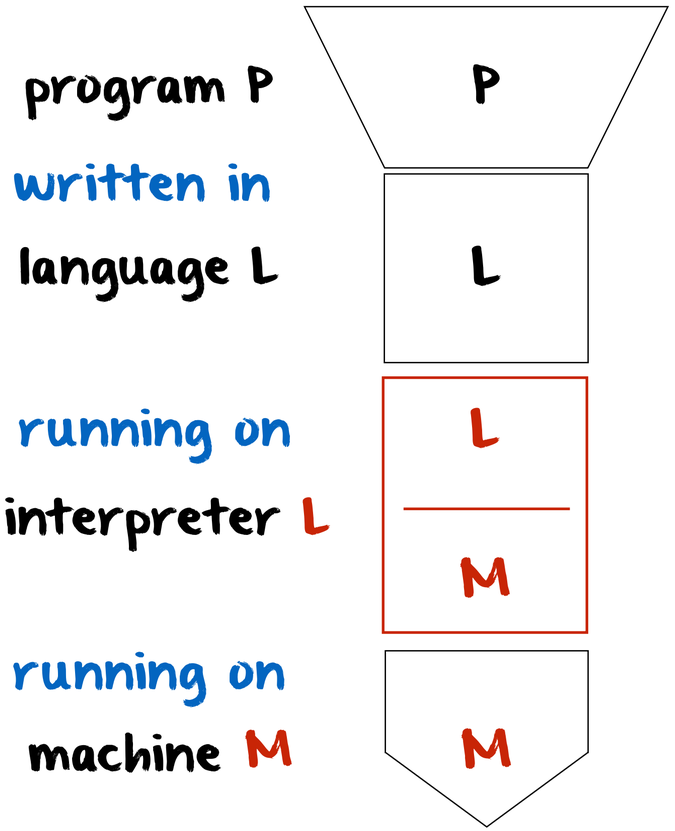
examples



solution!

executions and interpreters

concept



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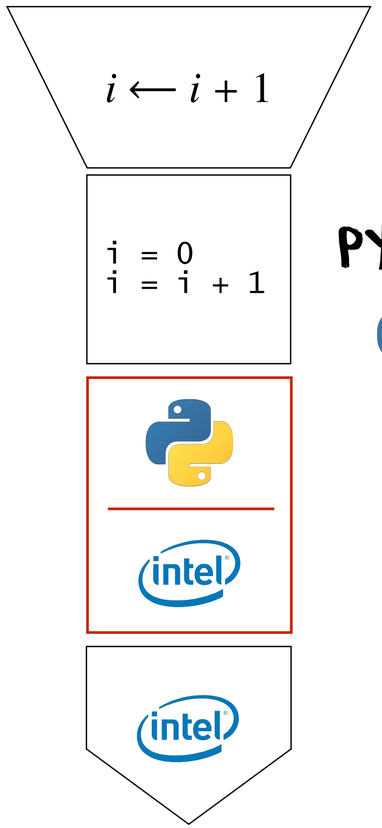
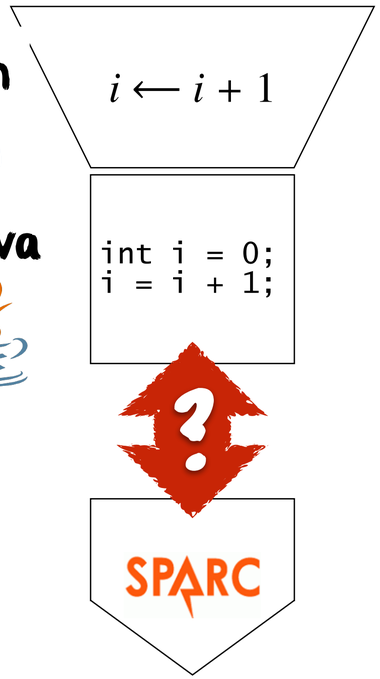
examples



an addition written in

python

java



executions and interpreters

concept

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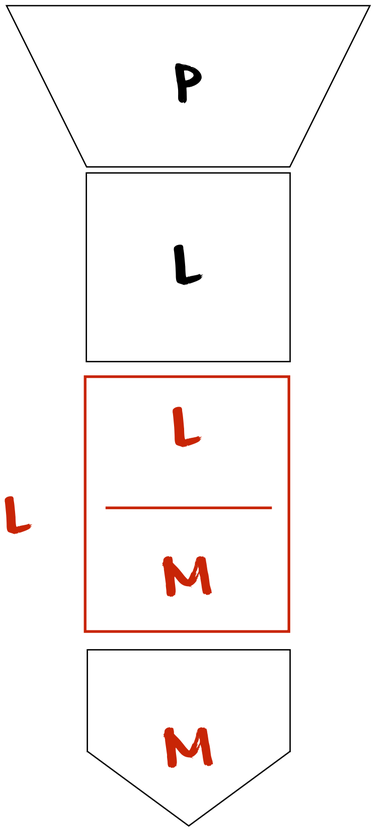
language L



running on

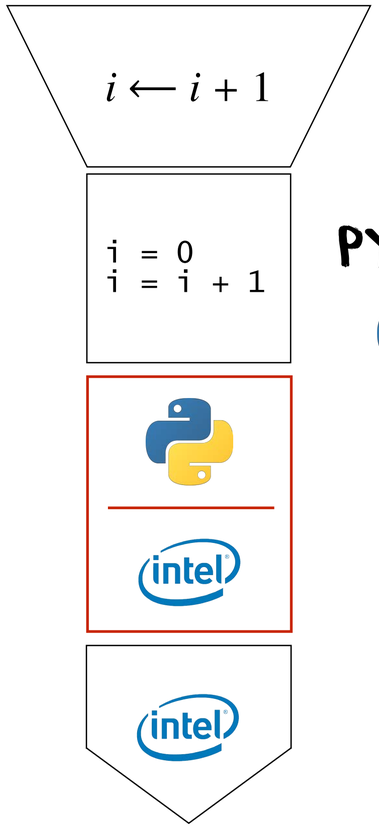
interpreter L

running on

machine M

an interpreter dynamically translates language L into language M

examples



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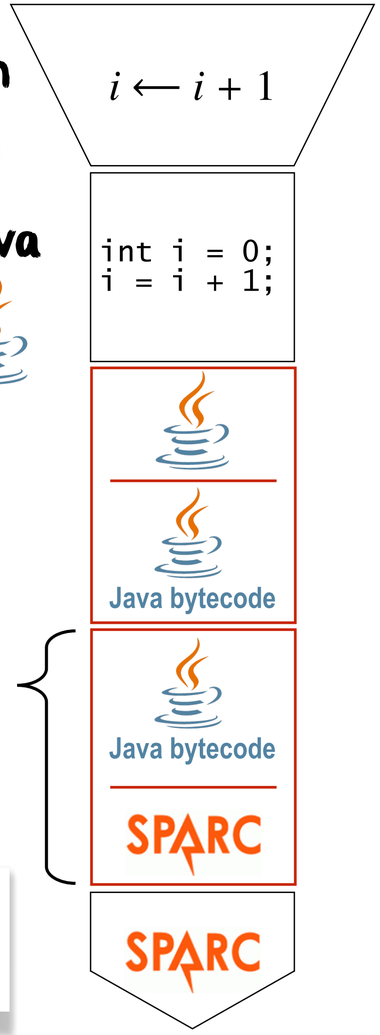


interpreter ⇔ emulator ⇔ virtual machine

what's a compiler

a program that translates
human-understandable source code to
machine-understandable byte code

```
public class Shopping

    private int id;
    private static int
    private ArrayList
    private ArrayList
    private double balance = 0.0;


    public ShoppingCart() {
        this.id = ++count;
        this.foods = new ArrayList<>();
        this.drinks = new ArrayList<>();
    }


    public double emptyShoppingCart() {
        foods.clear();
        drinks.clear();
        double tmp = balance;
        balance = 0.0;
        return tmp;
    }

    public double getBalance() {
        return balance;
    }
```

java compiler

0010010100101011000100101011001101001110011111001101010...

```
LDR   R3   R1
ADD   R3   R1   R2
STR   R3   R1
```

Java bytecode

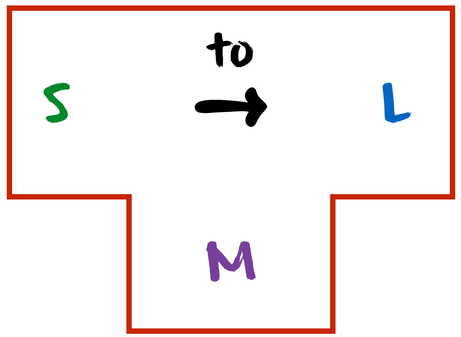
what's a compiler

concept

examples

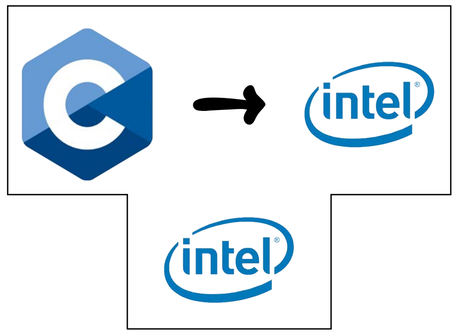
compiler translating

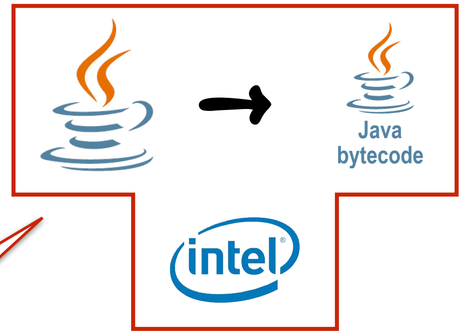
source language



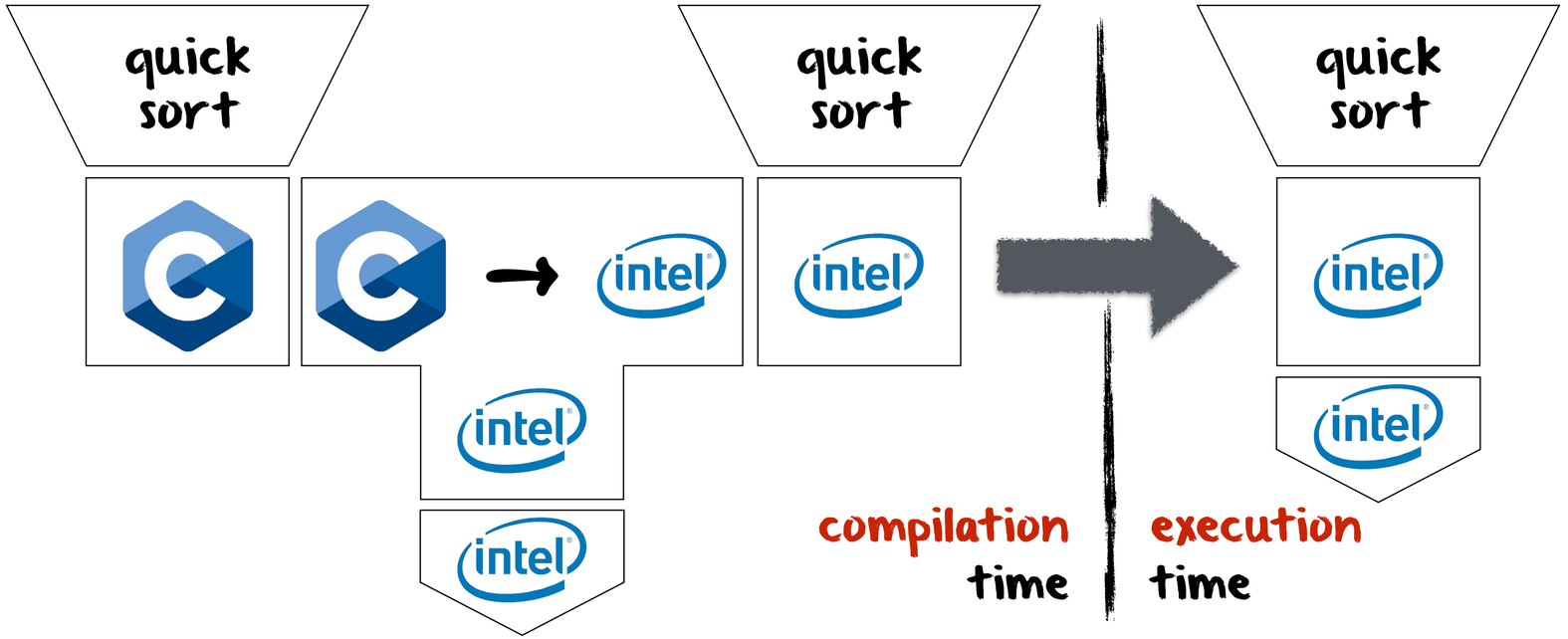
target language

implemented in M



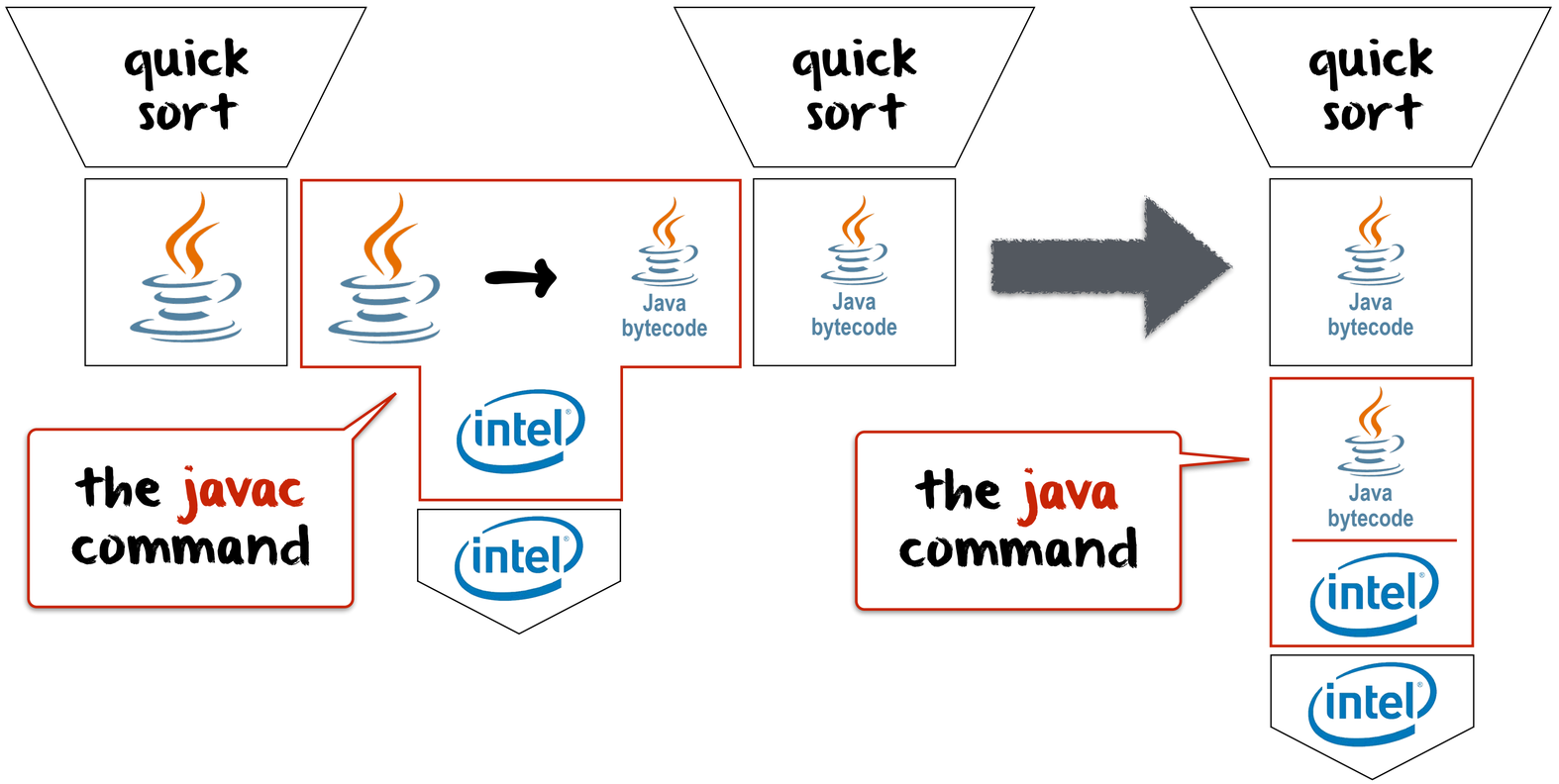


this is a cross-compiler

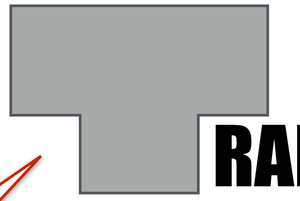


what's a compiler

the example of java



static vs. dynamic



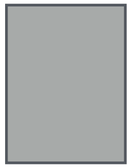
RANSLATION

the javac command

the translation occurs at compile time, before the execution, while the program is static

---

the java command



NTERPRETATION

the interpretation occurs at run time, during the execution, while the program is dynamic

what are runtime systems & libraries?

a library contains predefined bricks (functions, objects, etc.) that help create software, e.g., strings, dates, lists, input/output functions, etc.

a runtime system is the mortar that glues the various parts of software during execution

---

```
public class HelloWorld {

   public static void main(String[] args) {
      System.out.println("Hello World!");
   }

}
```

where does System.out come from?

where does String come from ?

where is args stored?

how is “Hello, world!” passed to println(…)?

what are runtime systems & libraries?

```
public class HelloWorld {

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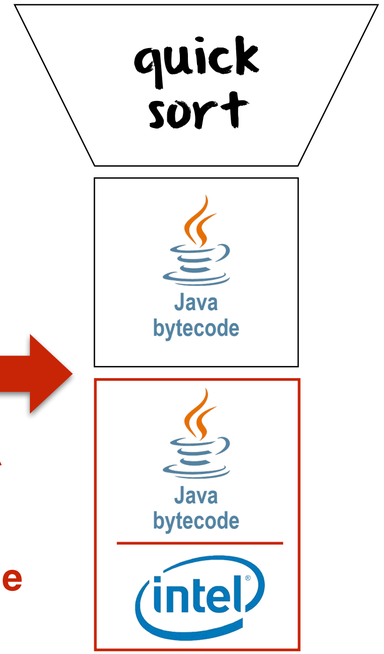
---

the answer is...



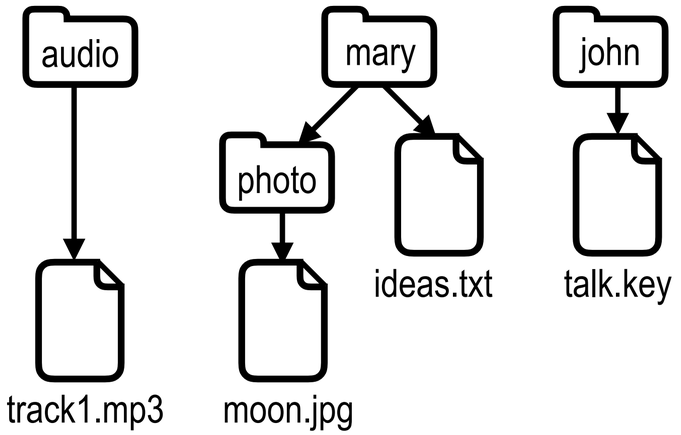
filesystems & command shells

a filesystem is a part of the operating system that allows users to manipulate data stored on some persistent storage, typically a disk

a terminal is a program that allows users to interact with the operating systems using a command line interface known as a shell

a shell is an interpreter for a specific scripting language that can be used either interactively, via a terminal, or launched as a program by providing it with a script file containing commands

filesystems



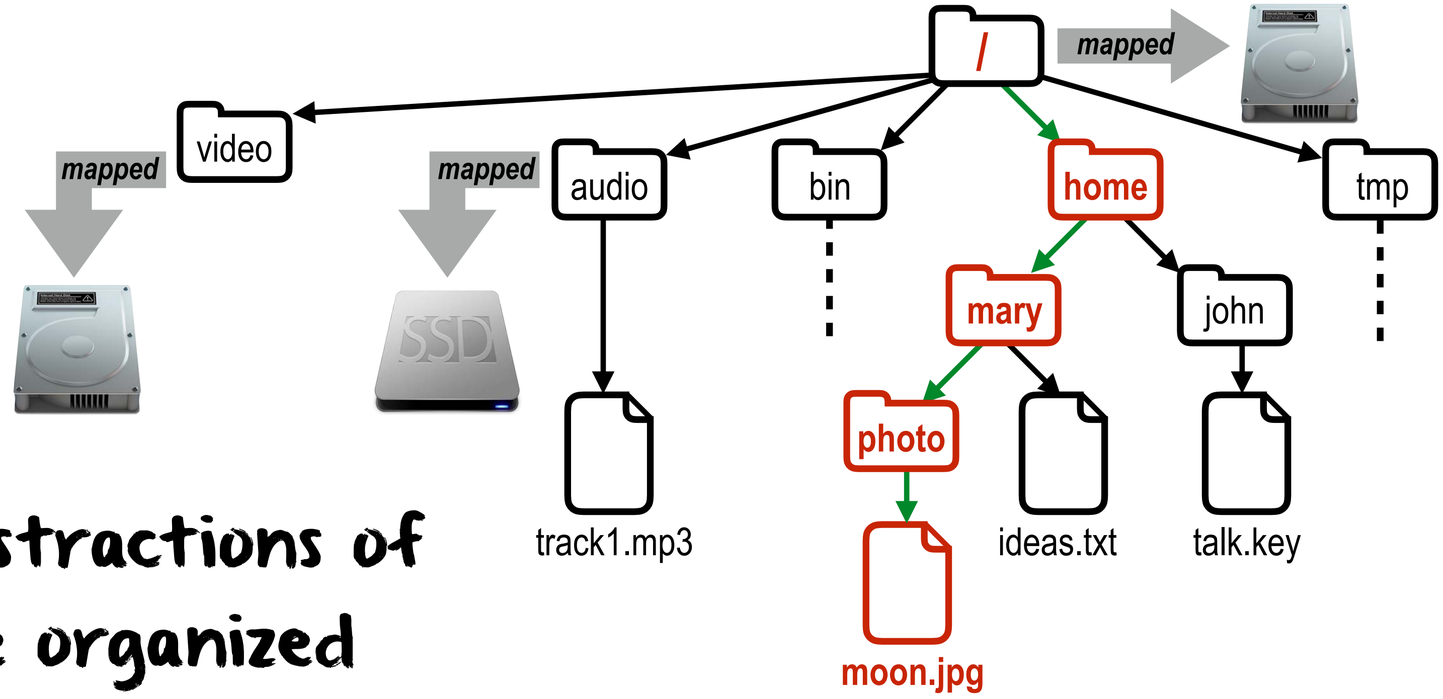
a filesystem is based on the abstractions of files and directories, which are organized and accessed via paths in a namespace

a file is an abstraction representing a sequence of bits stored on some persistent storage; this sequence of bits is the content of the file

a directory is an abstraction representing a group of files and directories; the references to those files and directories constitute the content of the directory

in addition to their content, files and directories contains attributes, among which their name, their type, their size, their access rights, etc.

filesystems



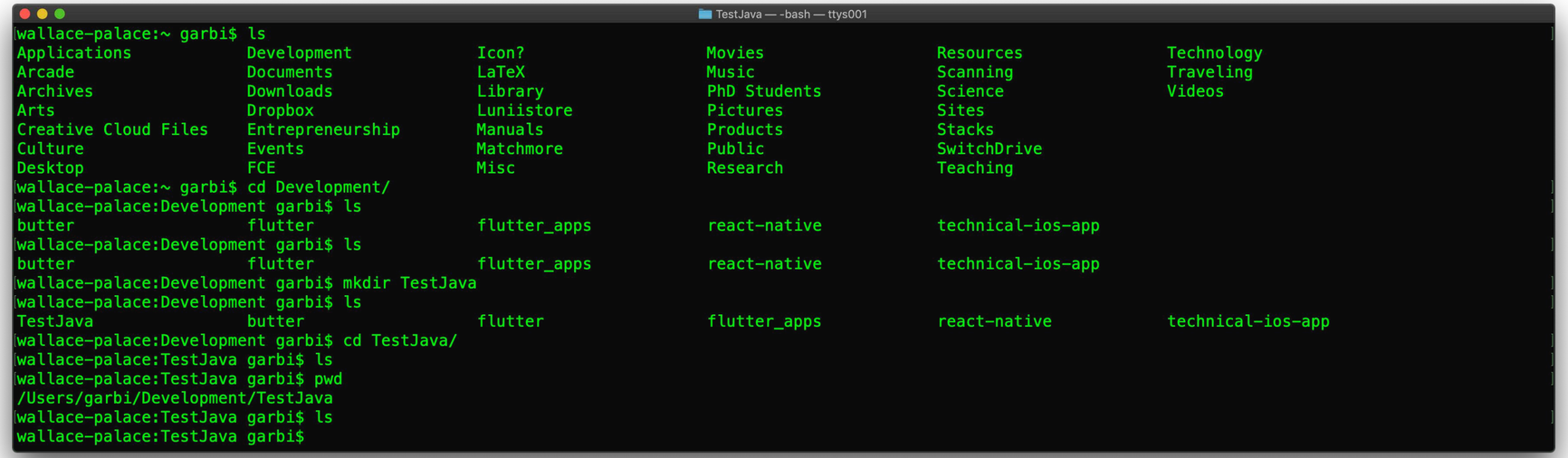
a filesystem is based on the abstractions of files and directories, which are organized and accessed via paths in a namespace

path: /home/mary/photo/moon.jpg

a namespace maps files and directories to their physical location (disk) on the persistent storage, via a hierarchy of names organized as a tree

a path is a sequence of names (separated by some special character) that specifies a unique location in the filesystem, starting from the root of the namespace tree

command shells



Basic Bash Commands

ls	list files and directories in the current working directory
ls -la	list all files and directories with details in the current working directory
cd *directory*	change the working directory to be *directory*
cd ~	change the working directory to be your home directory
cd ..	change the working directory to be the parent directory
pwd	print the current working directory
mkdir *directory*	create a new directory named *directory*
more *textfile*	display the content of the file named *textfile* one page at a time
man *command*	display help about the command named *command*