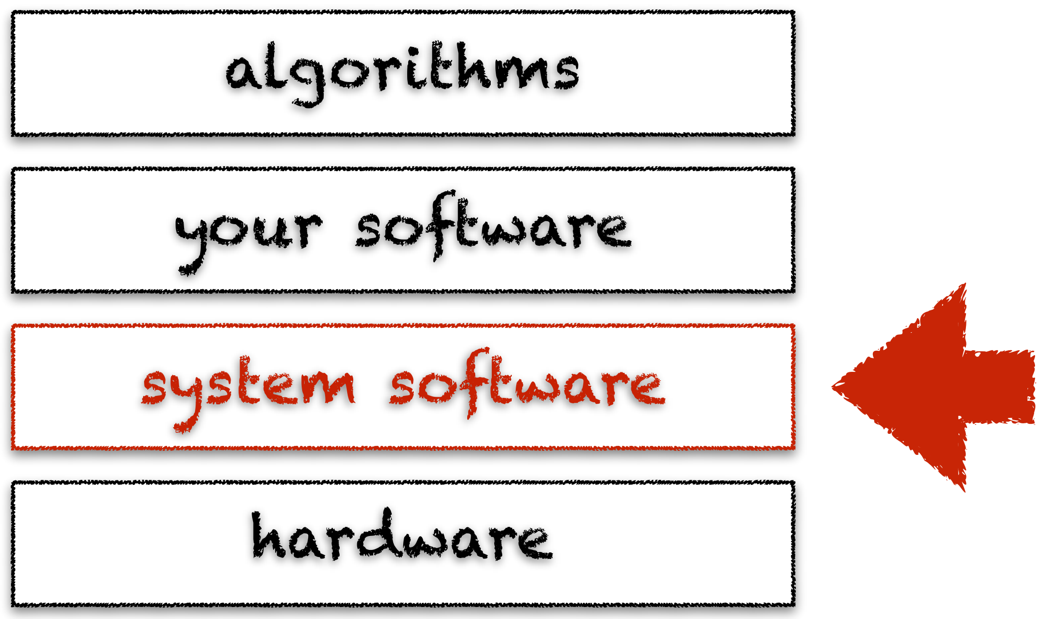
system software

learning objectives



algorithms

your software

system software

hardware

- 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

examples 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

the
sharing era

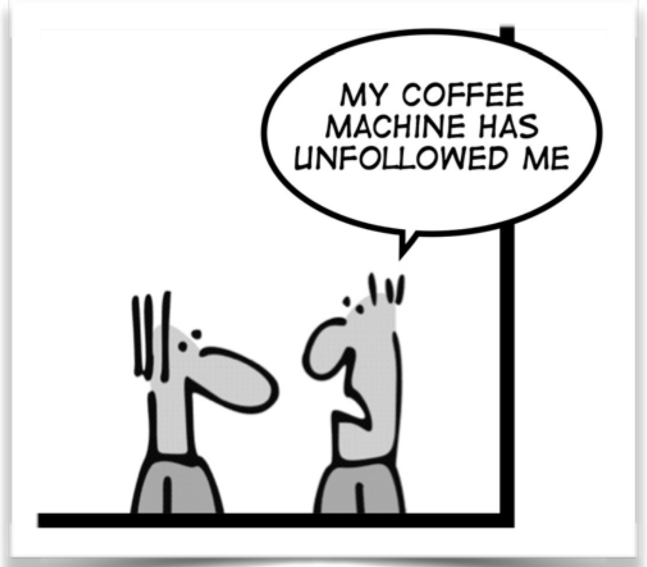
- 1970s multi-user & time-sharing

the
personal era

- 1980s personal desktop computers

the
communication era

- 1990s distributed systems
- 2000s mobile systems
- 2010s ubiquitous systems

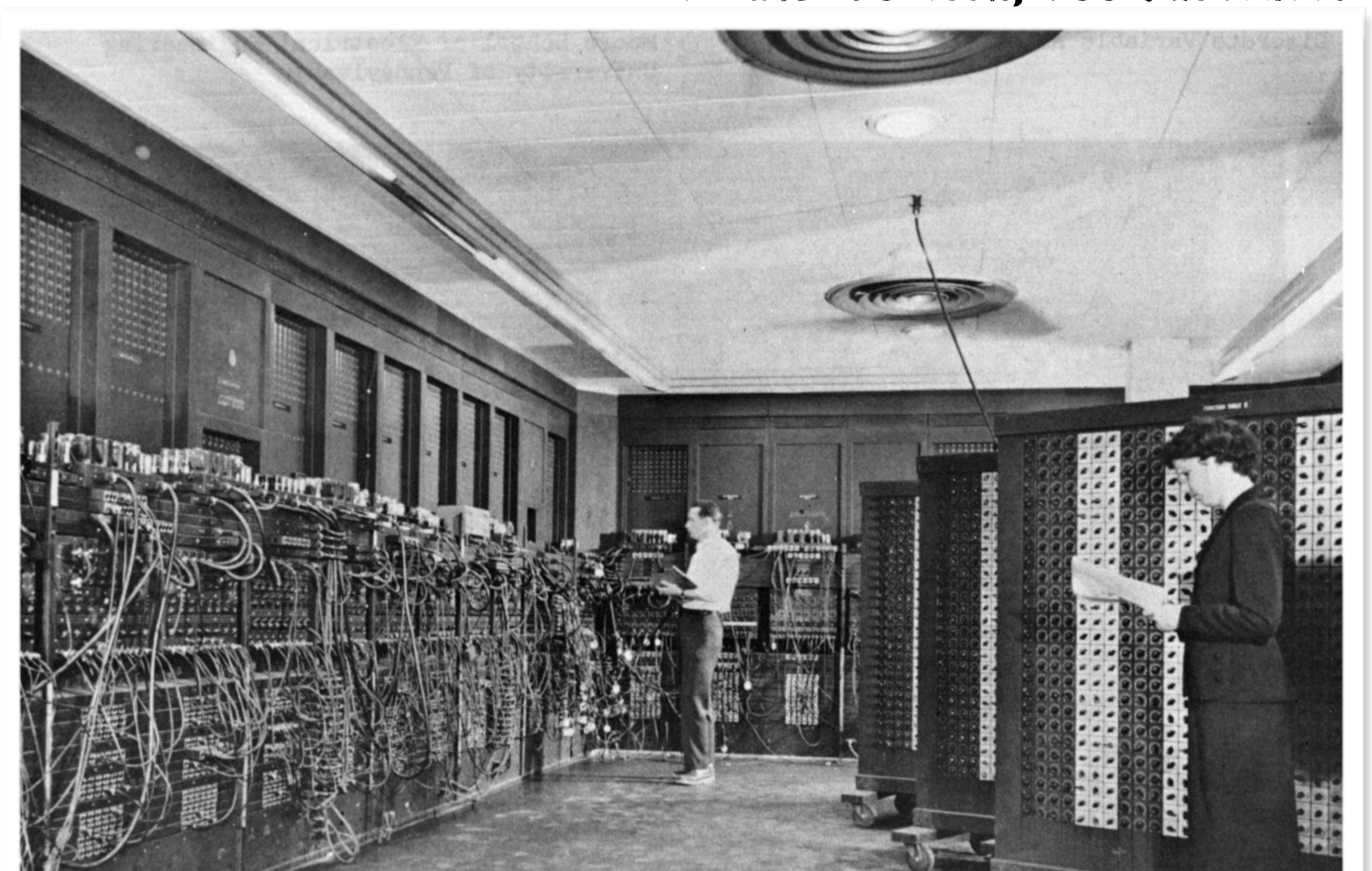


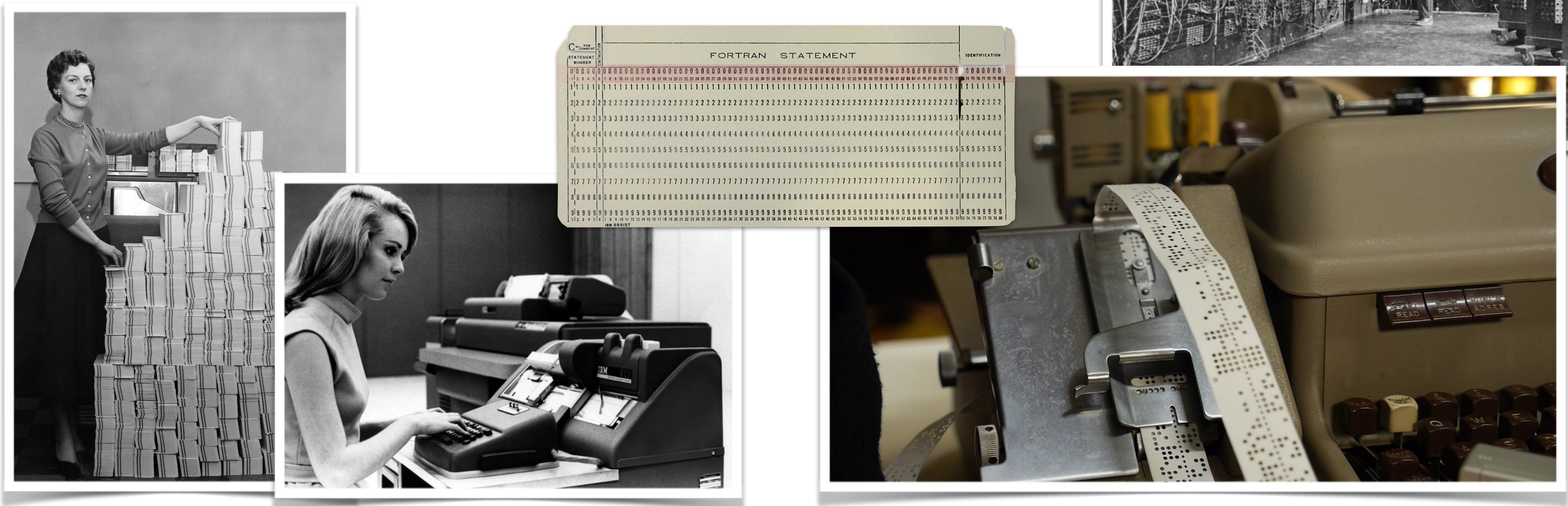
the digital
transformation era

no systems software

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

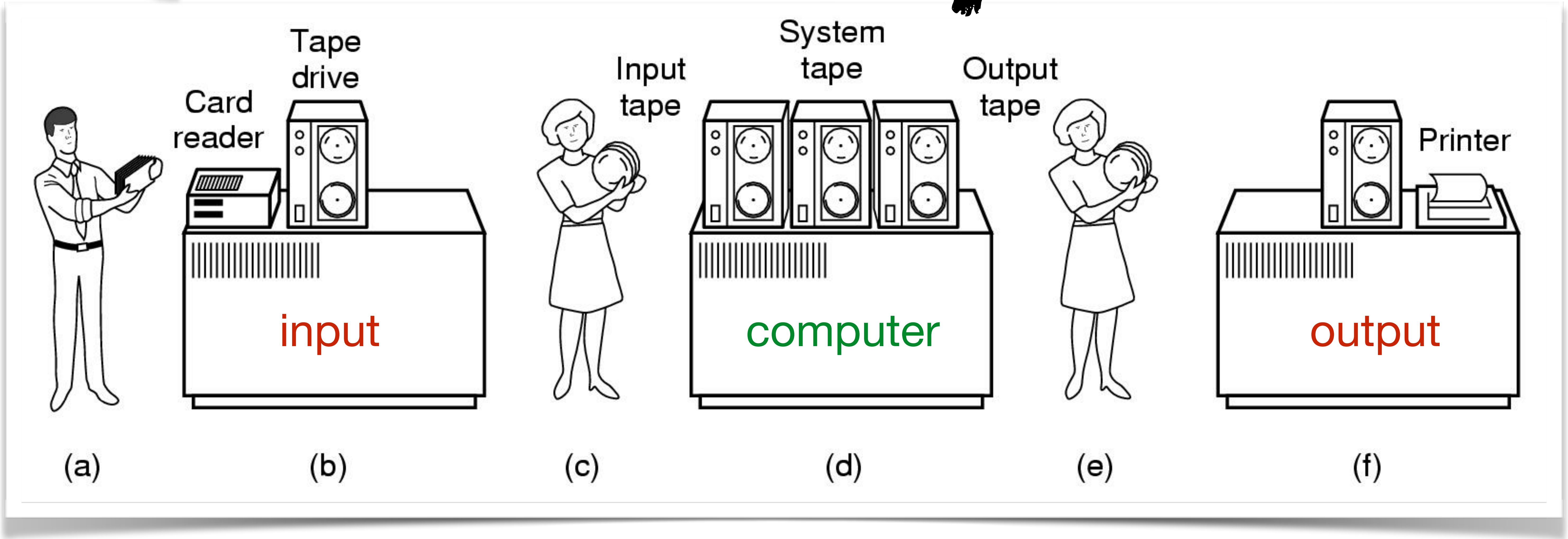
ENIAC: 30 tons, 200 kilowatts





1960s

batch systems



(a) put cards into reader

(b) read cards to tape

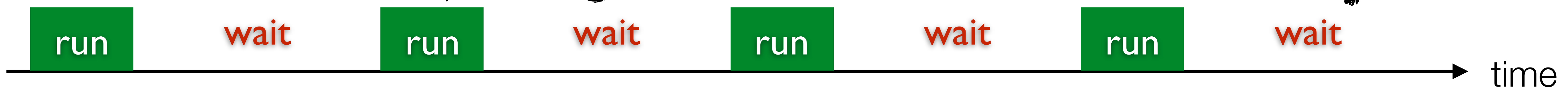
(c) put input tape on computer

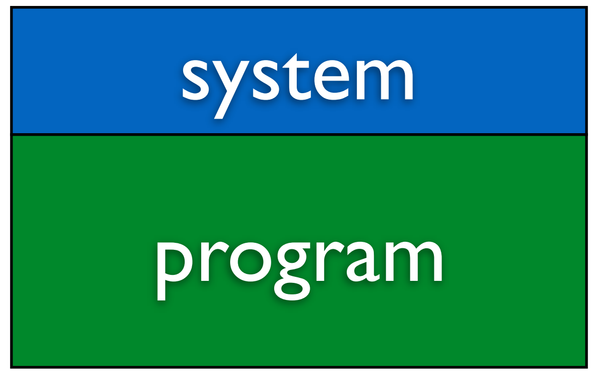
(d) perform the computation

(e) put output tape on printer

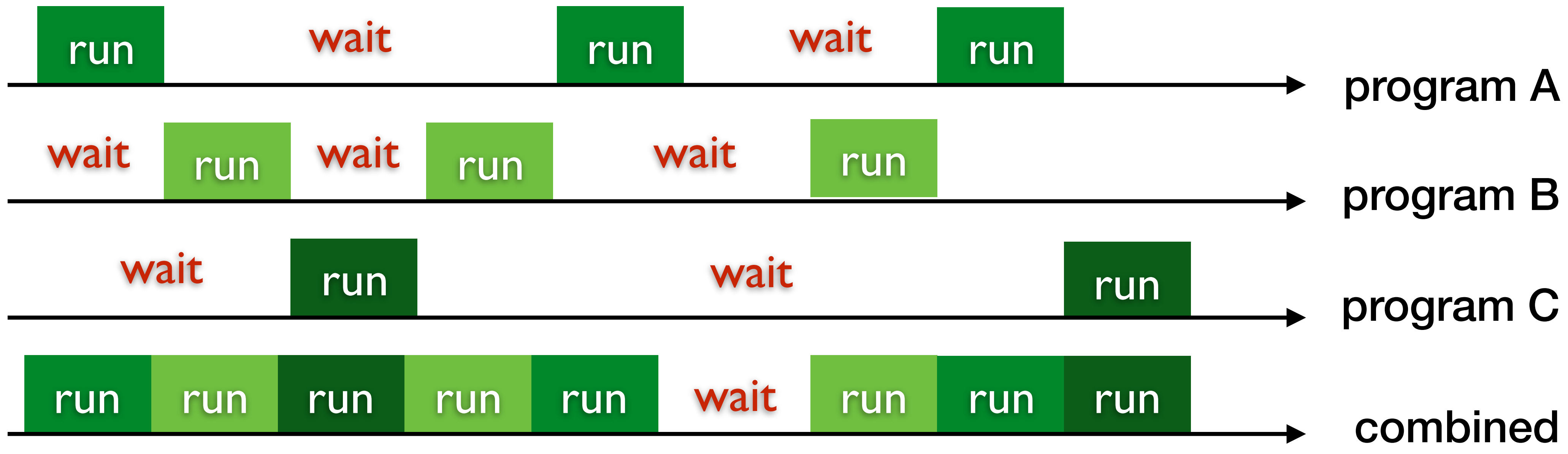
(f) print output tape on paper

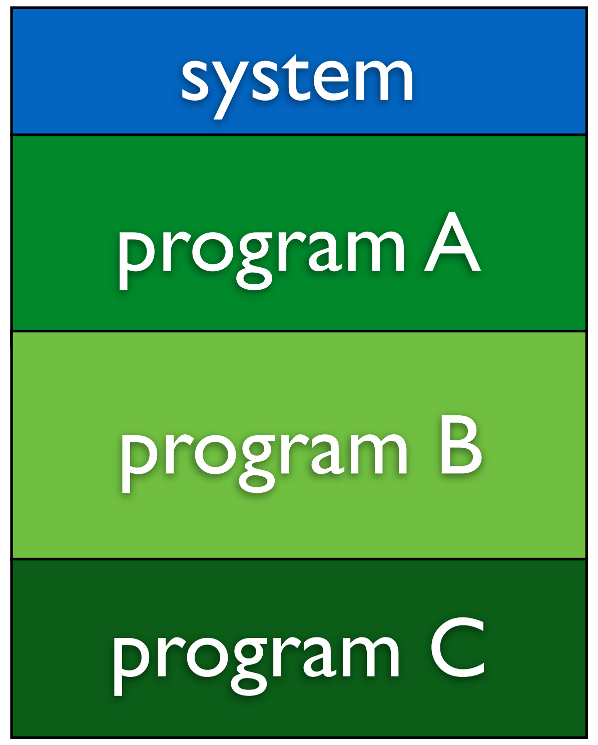
- first uni-programmed batch systems





- then multi-programmed batch systems





1970s multi-user & time-sharing

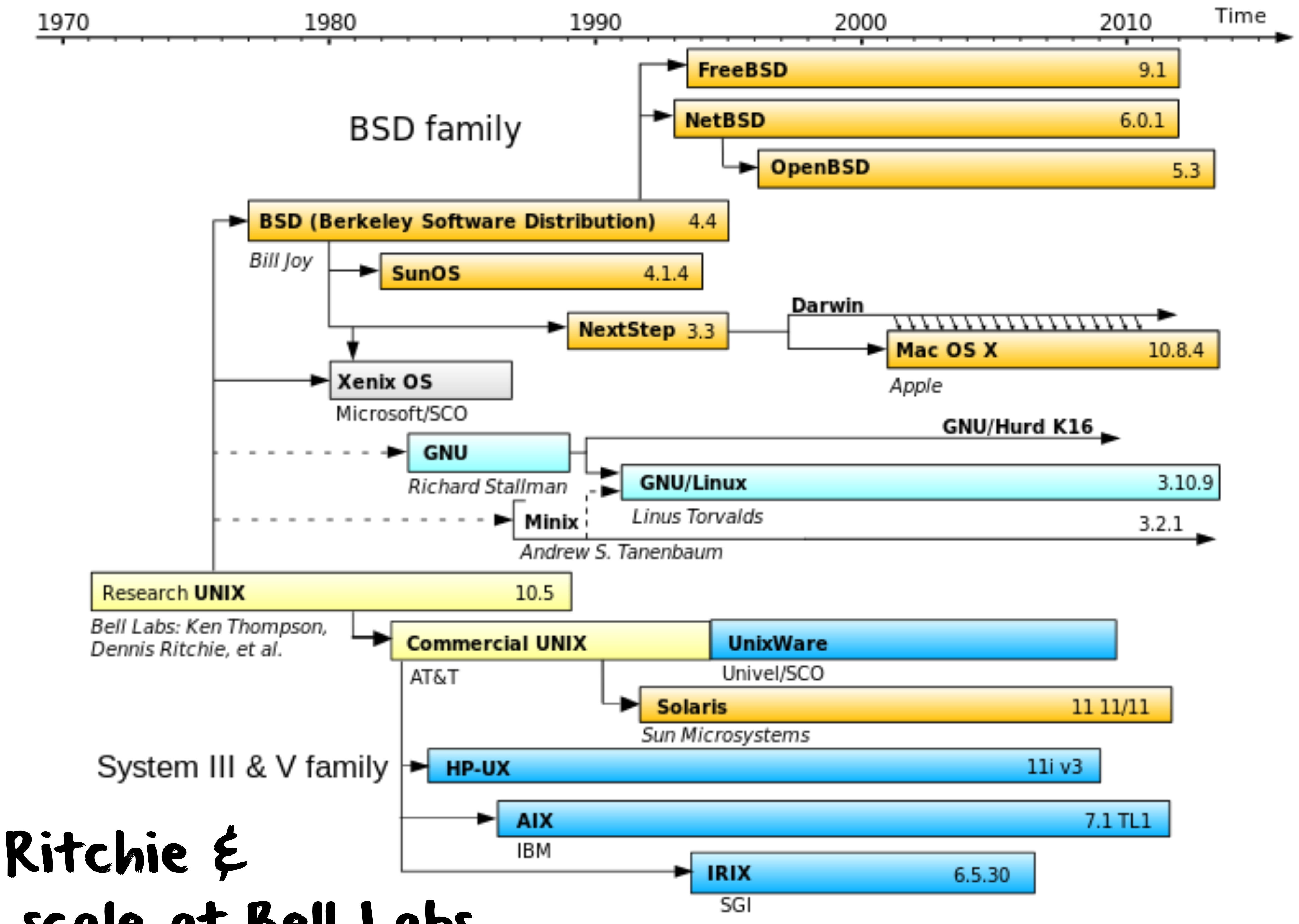
from Multics...

Ken Thompson &Dennis Ritchie @ Bell Labs

...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.)

Unix



- 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

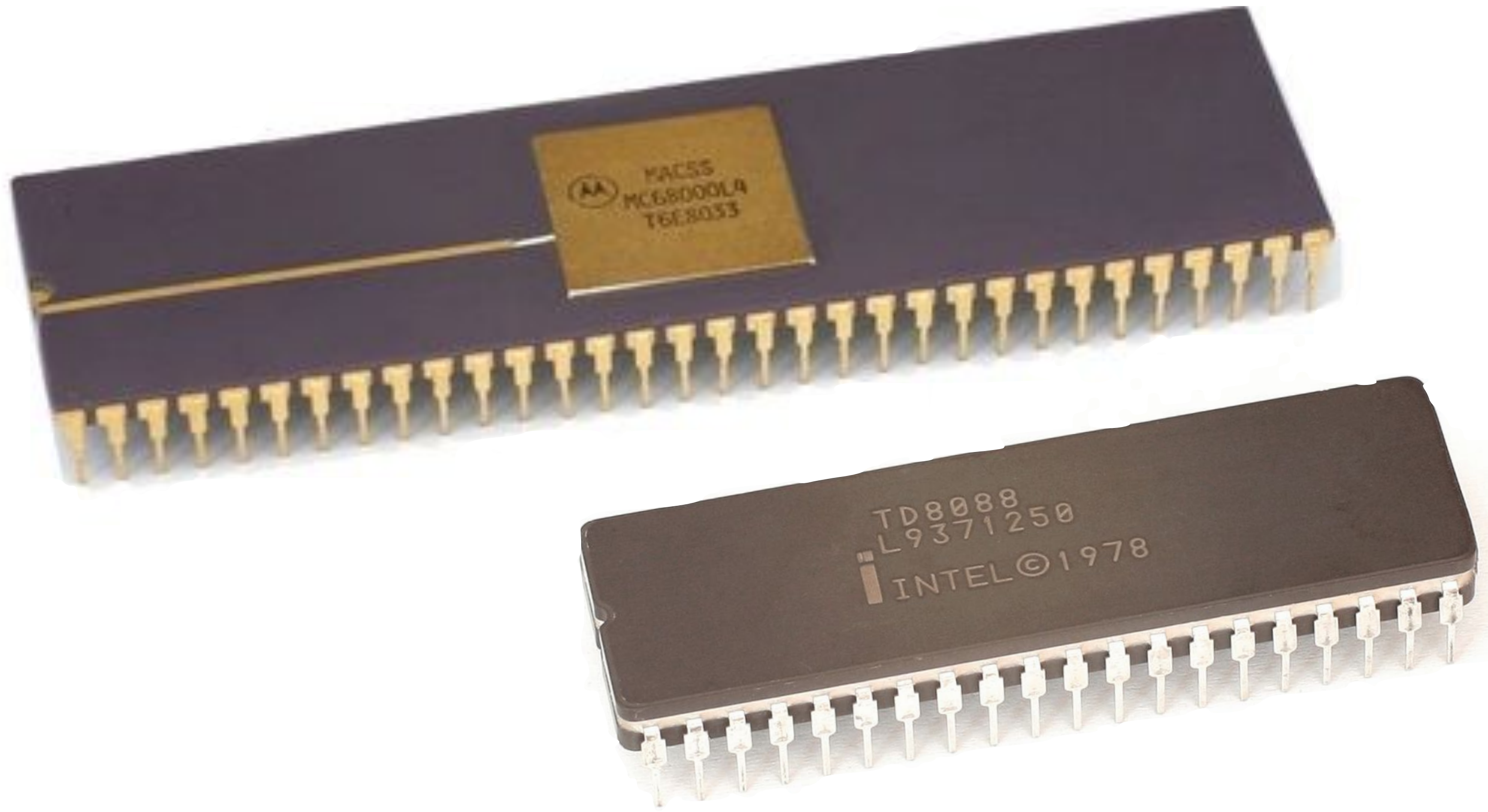
how did we get there?

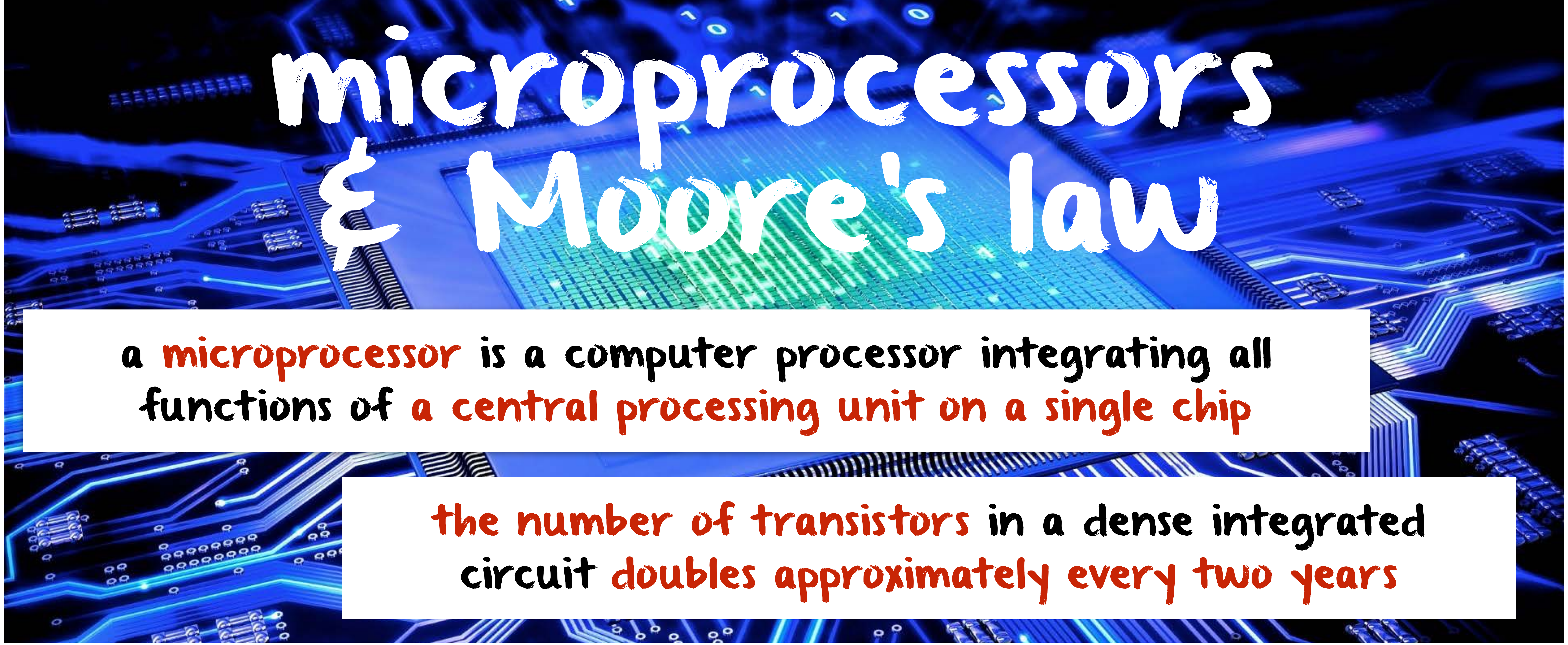
the invention of the microprocessor

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**

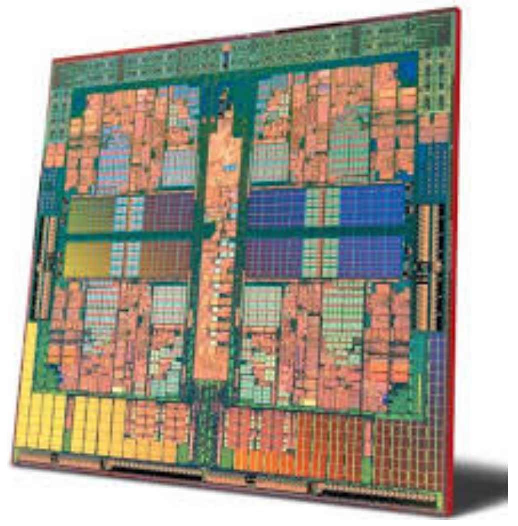
the number of transistors in a dense integrated circuit **doubles approximately every two years**

- 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**

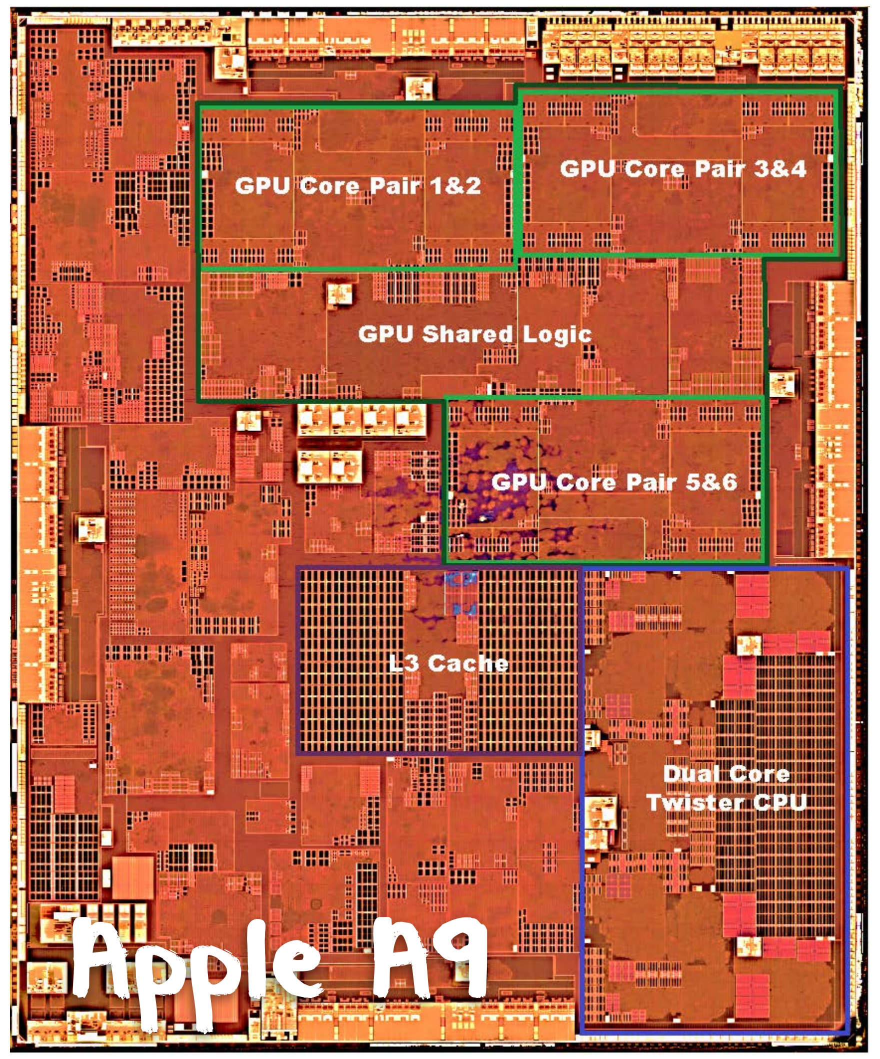
writing system software is about mastering exponential complexity

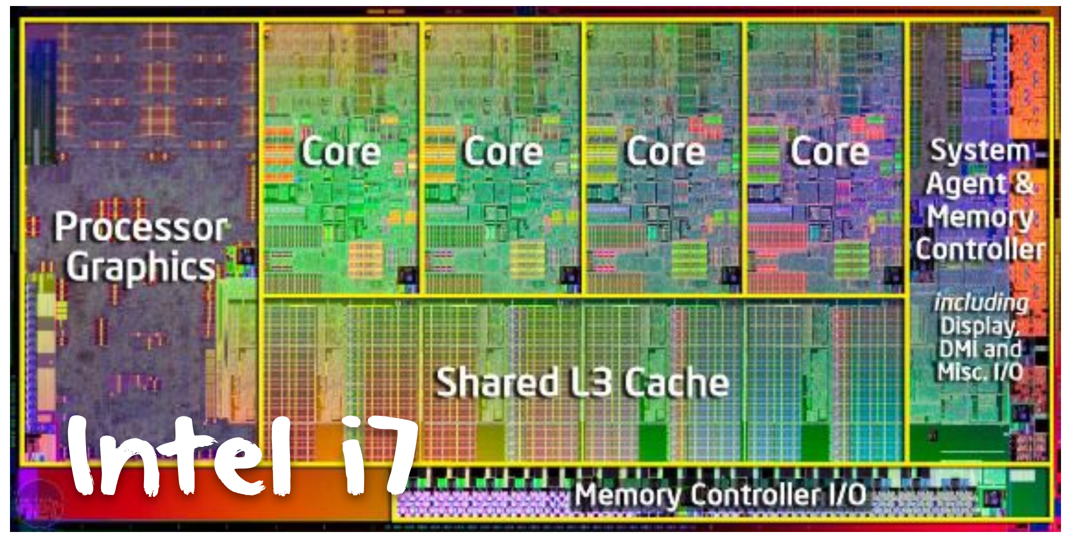
As long as there were no machines, programming was no problem at all; when we had a few weak computers, programming became a mild problem and now that we have gigantic computers, programming has become an equally gigantic problem. In this sense the electronic industry has not solved a single problem,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

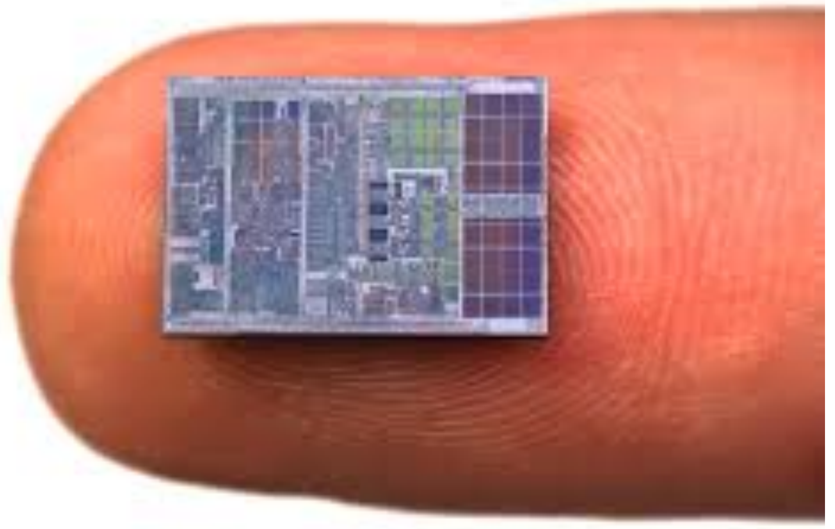
Edgster Dijkstra, The Humble Programmer. Communication of the ACM, vol. 15, no. 10. October 1972. Turing Award Lecture.



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

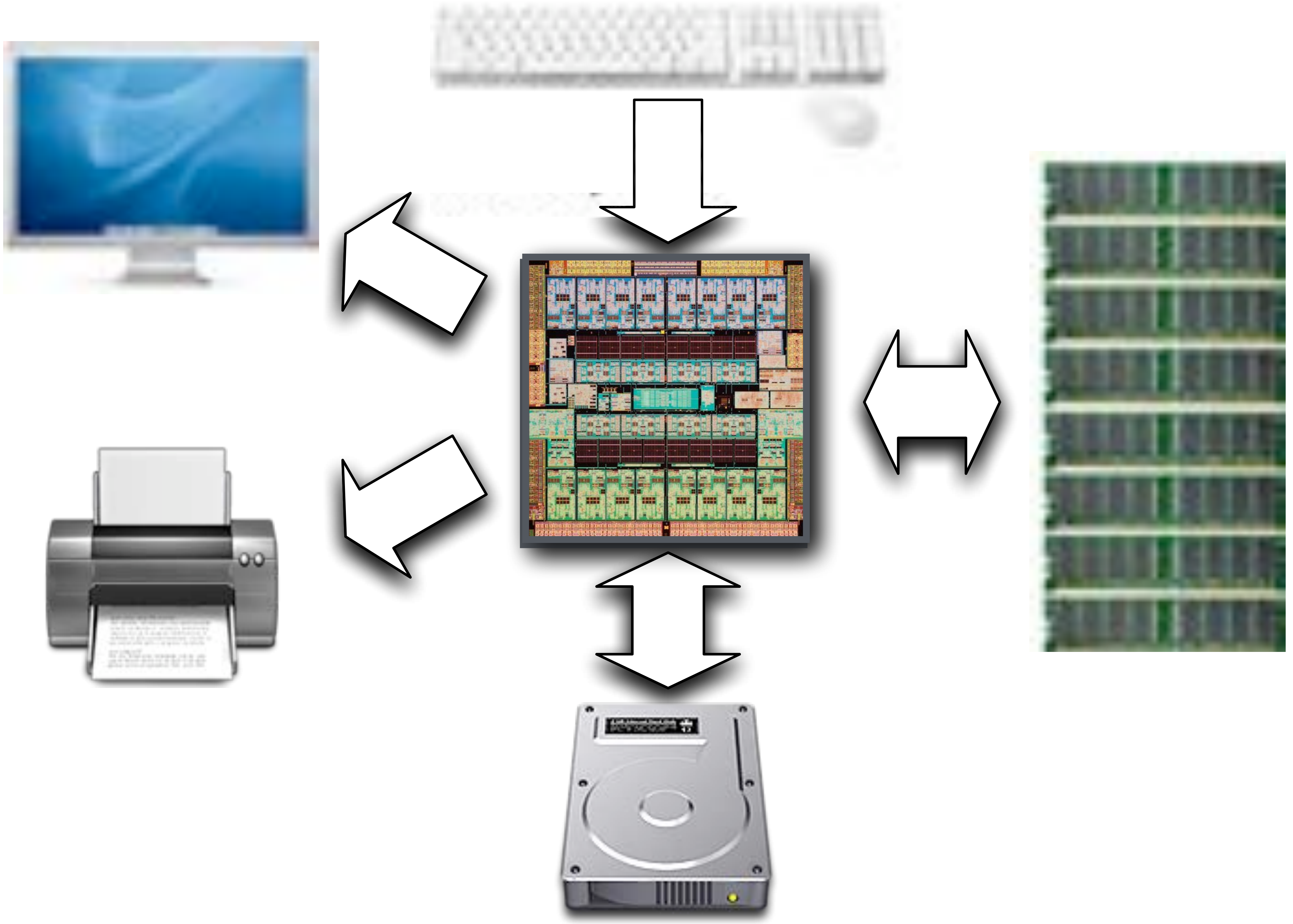
2000s: my phone is my computer

- smartphones & tablets as computers
- generalization of wireless networks

2010s: everything is a computer

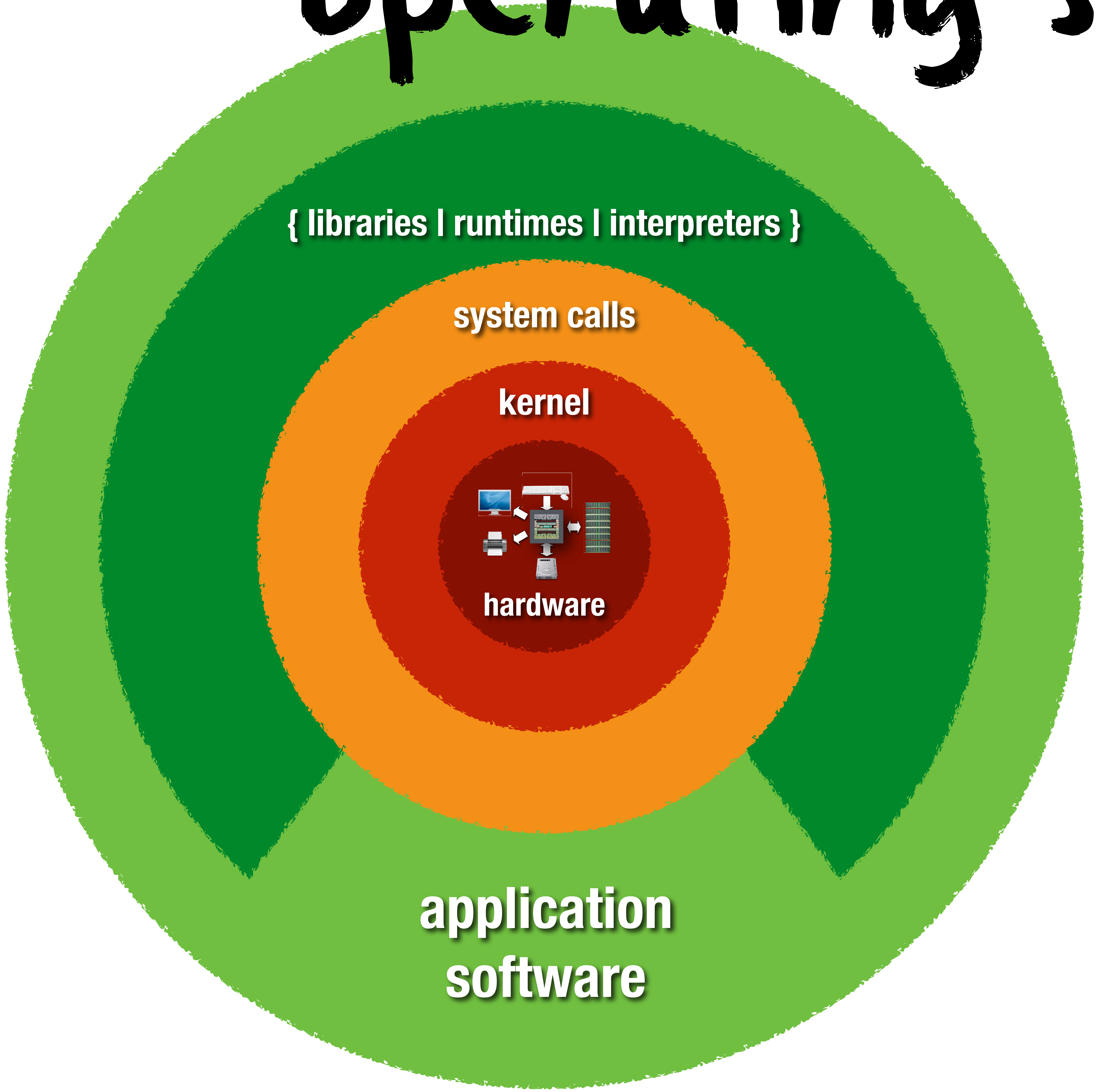
- smart objects & the Internet of things
- personal networks connected to the cloud

operating system



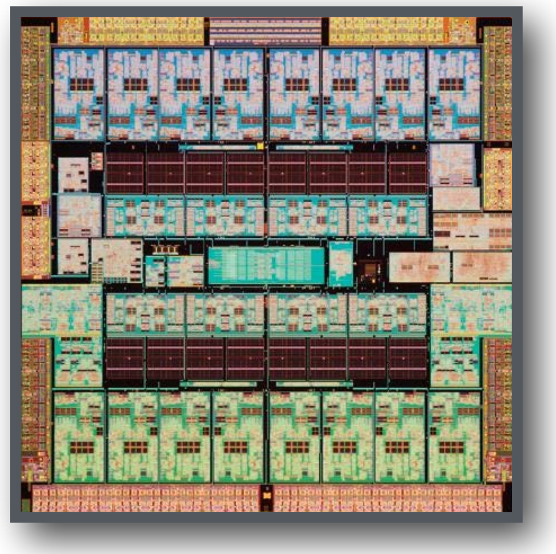
controls the access to hardware resources (cpu, memory, input/output devices, etc.) and acts as an interface with application software

operating system

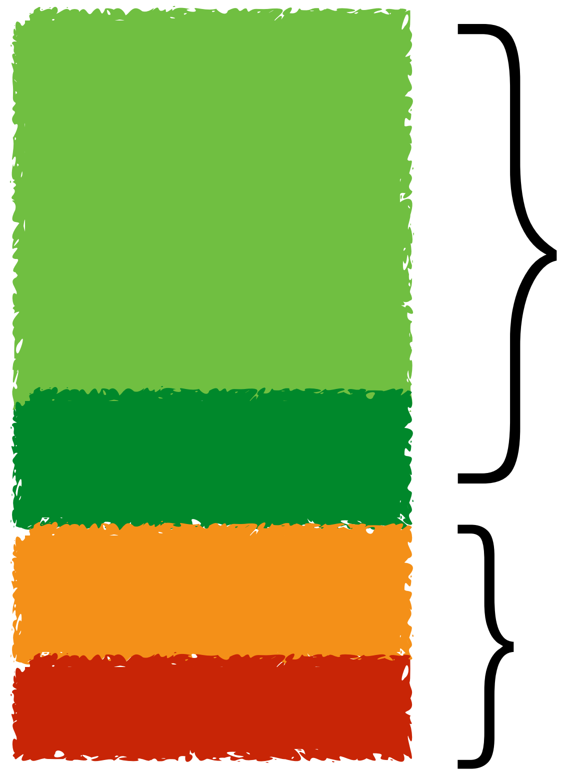


processor modes

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



memory protection


user space accessed in user mode
kernel space accessed in kernel mode

operating system

resource management

- cpu: process management
  - memory: memory management
    - input/output: i/0 management
      - storage: storage and file management

- keyboard, mouse, display
- touch screen, haptic interface, network
- printer, audio device, connectors (usb, dvi, etc.)
- compass, accelerometer, global positioning system
- etc...

	reality (physical resources)	abstraction (virtual resources)
CPU	***n parallel cores***	***m concurrent threads****, with* ***m*** ≫ ***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*** ≅ ***16 ×*** 10^6 ***terabytes*** ≅ ***16 ×*** 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*** ≫ ***i***

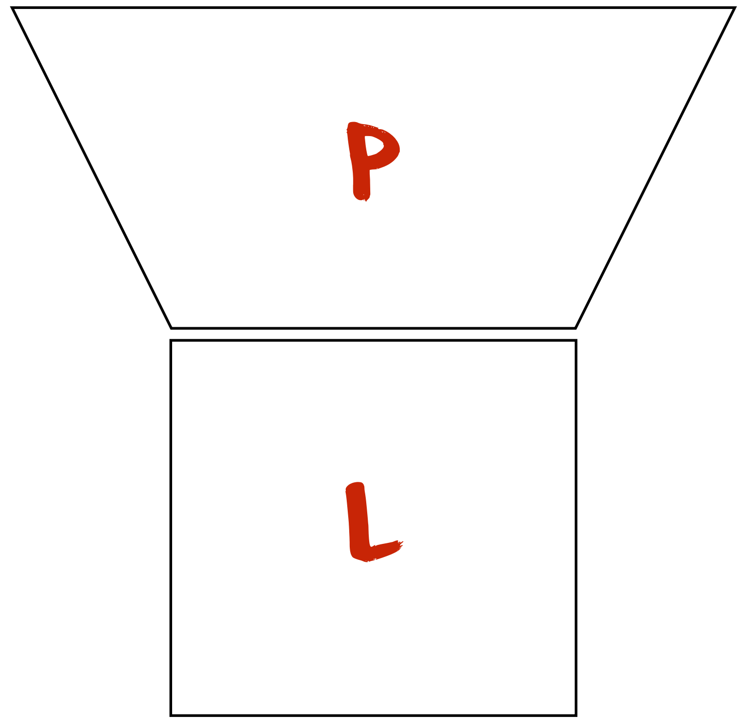
executions and interpreters

concept

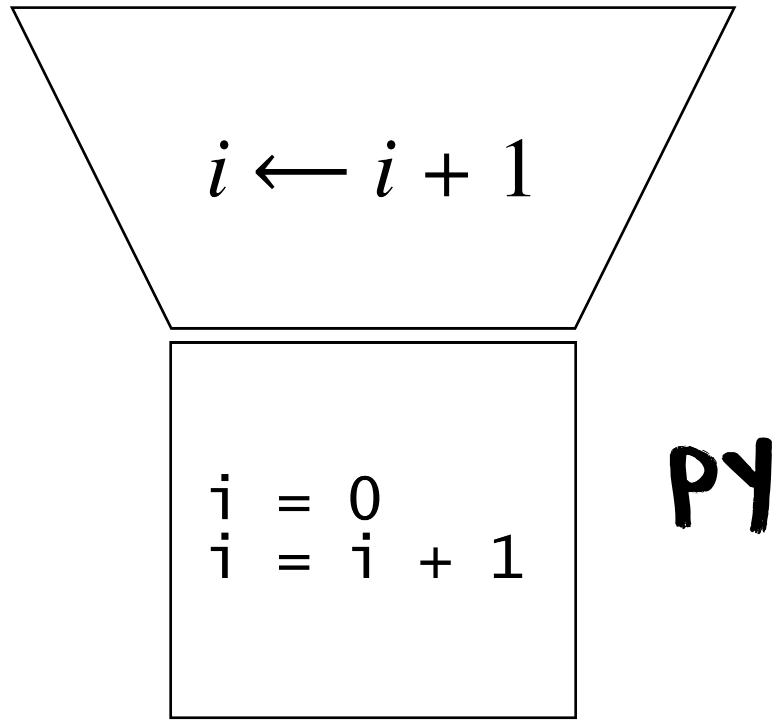
program P

written in

language L



examples



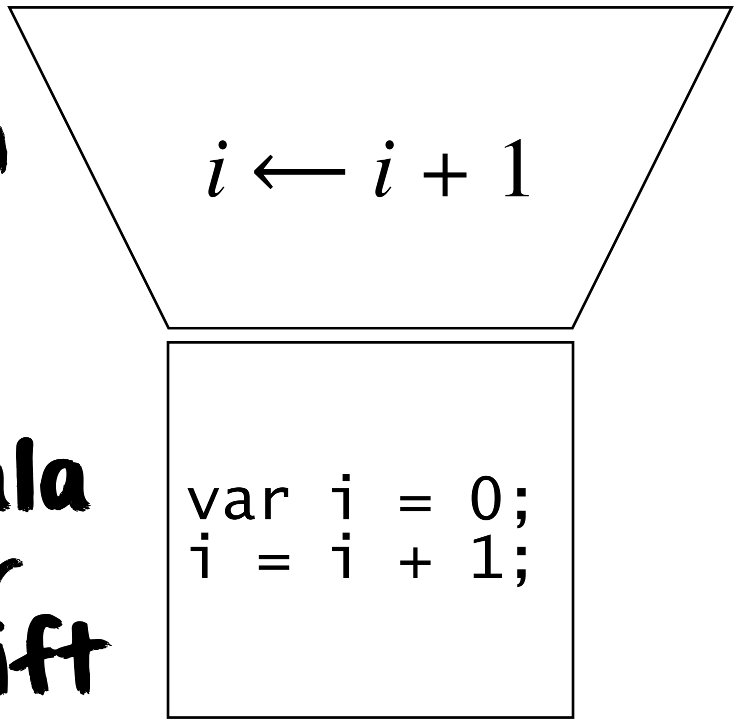
```
i = 0
i = i + 1
```

an addition

written in

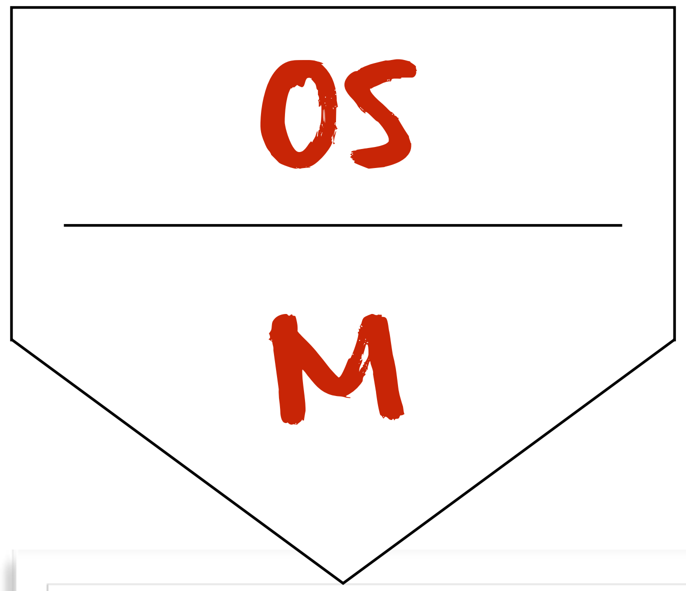
python

scala
or
swift

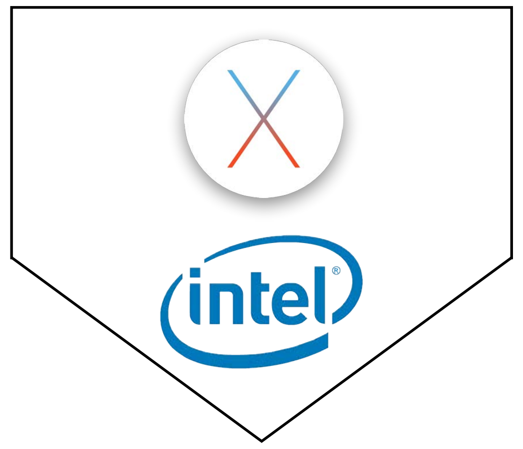


```
var i = 0;
i = i + 1;
```

operating system OS
controlling machine
executing language M



Samsung S7
running Android
on ARM



MacBook Pro
running OS X
on Intel

solaris
SPARC

Oracle Server
running Solaris
on SPARC

machine language M ⇔ instruction set ⇔ byte code

executions and interpreters

concept

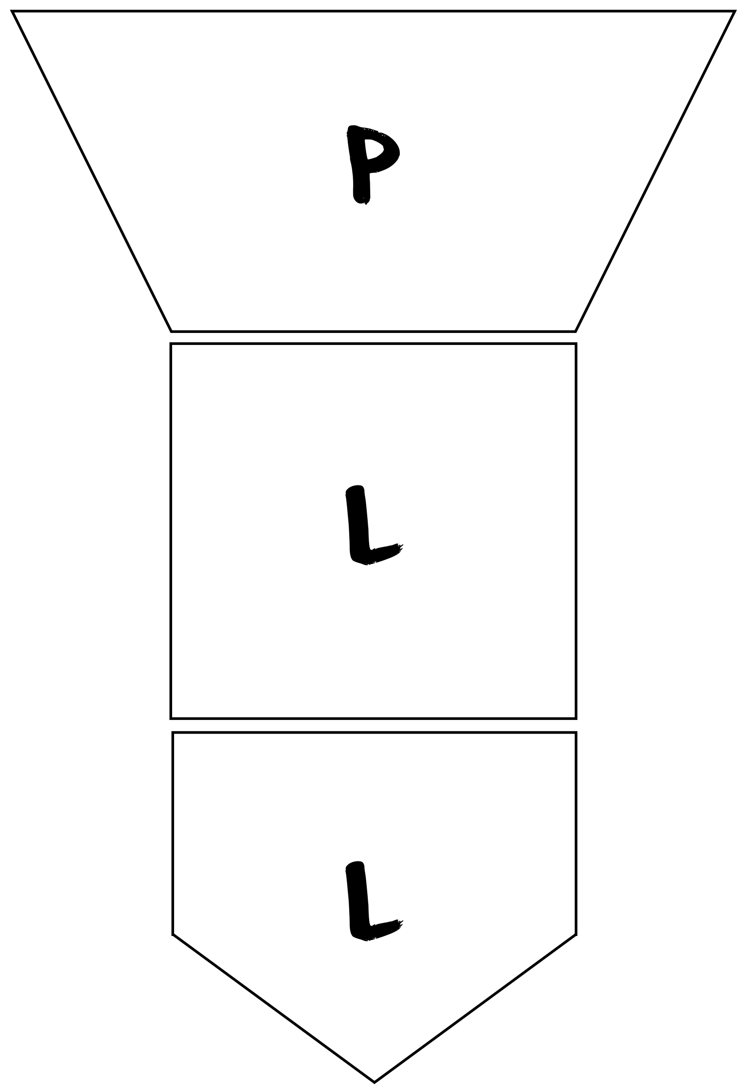
program P

written in

language L

running on

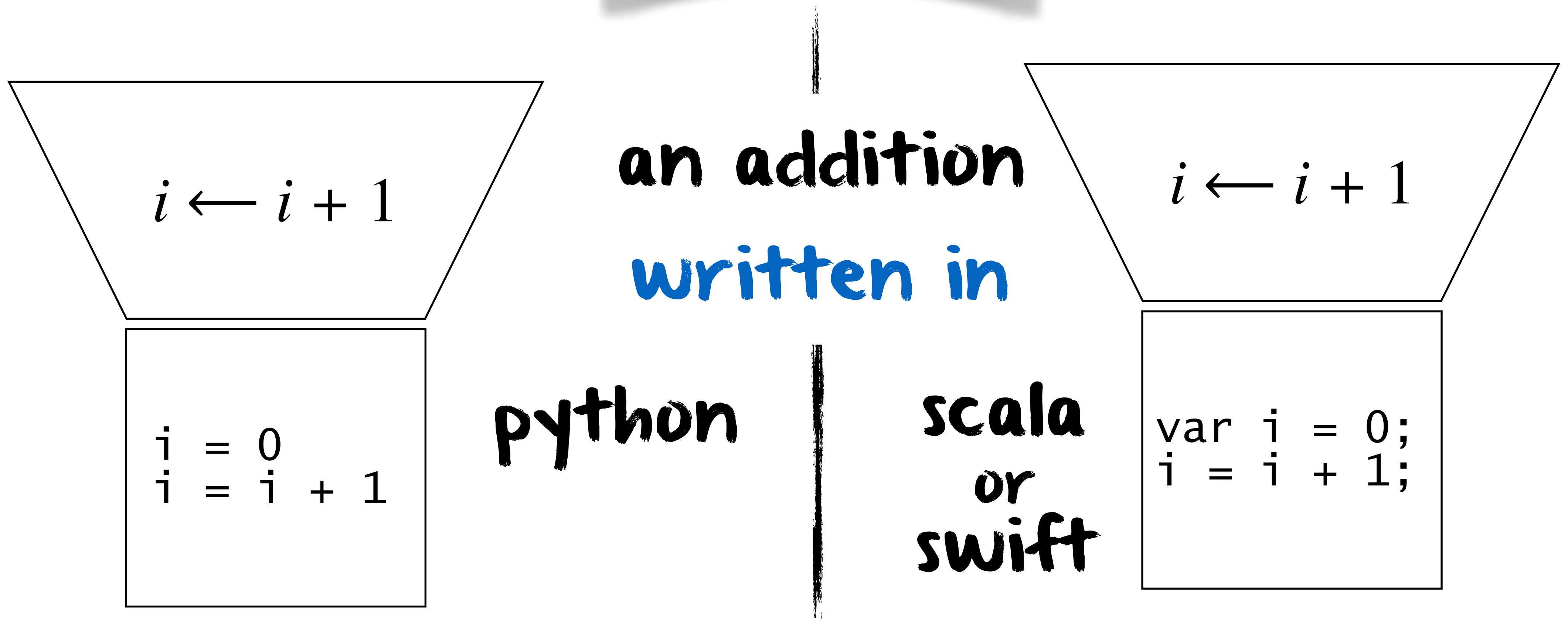
machine L



program language must match machine language

we forget about the operating system for now

examples



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an addition

written in

python | scala or swift

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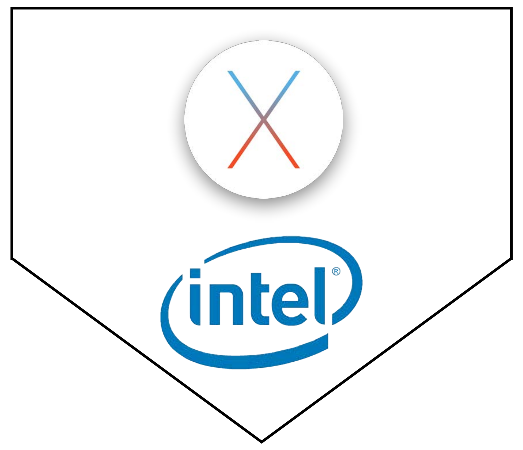

MacBook Pro running OS X on Intel

solaris
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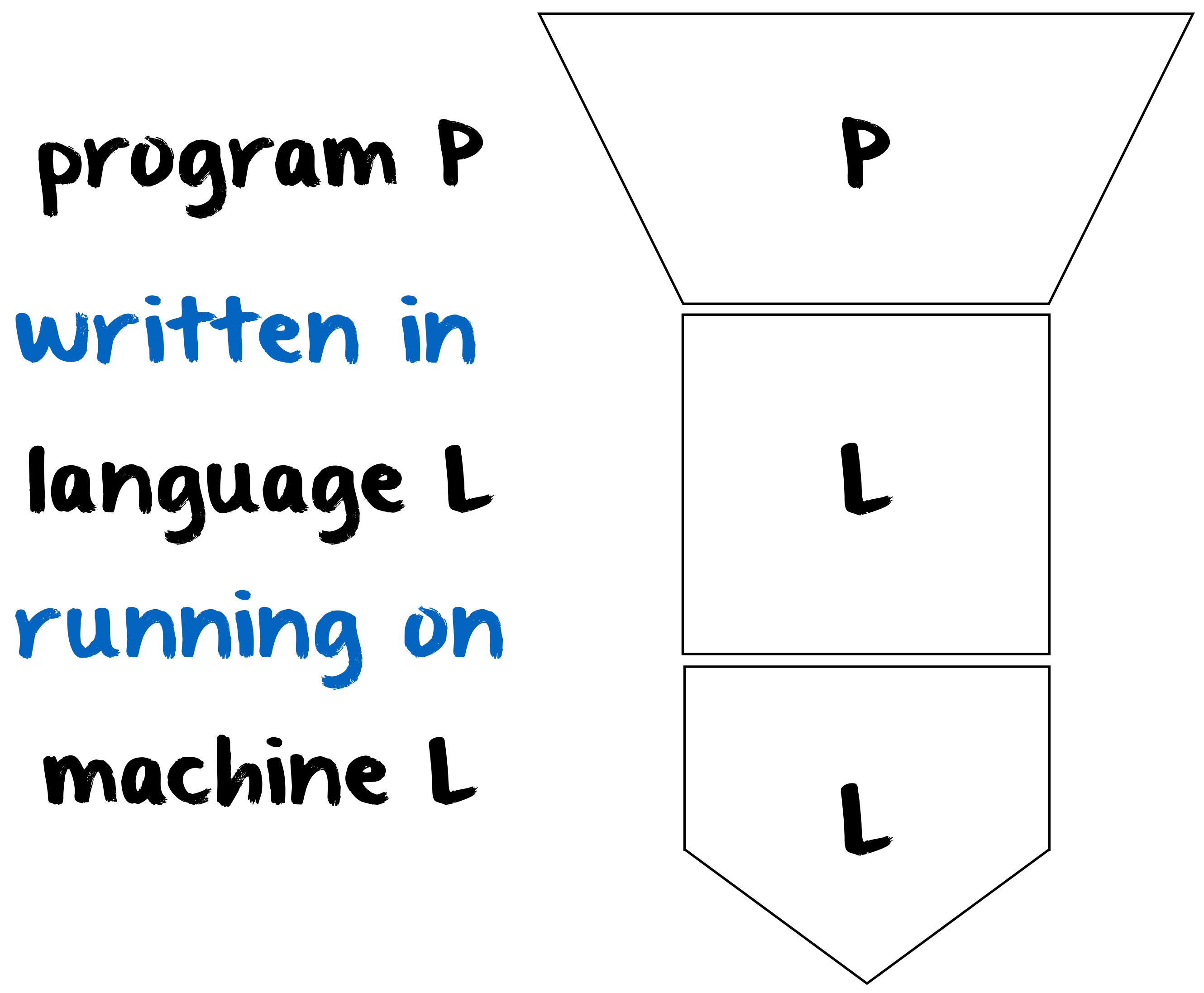
executions and interpreters

concept



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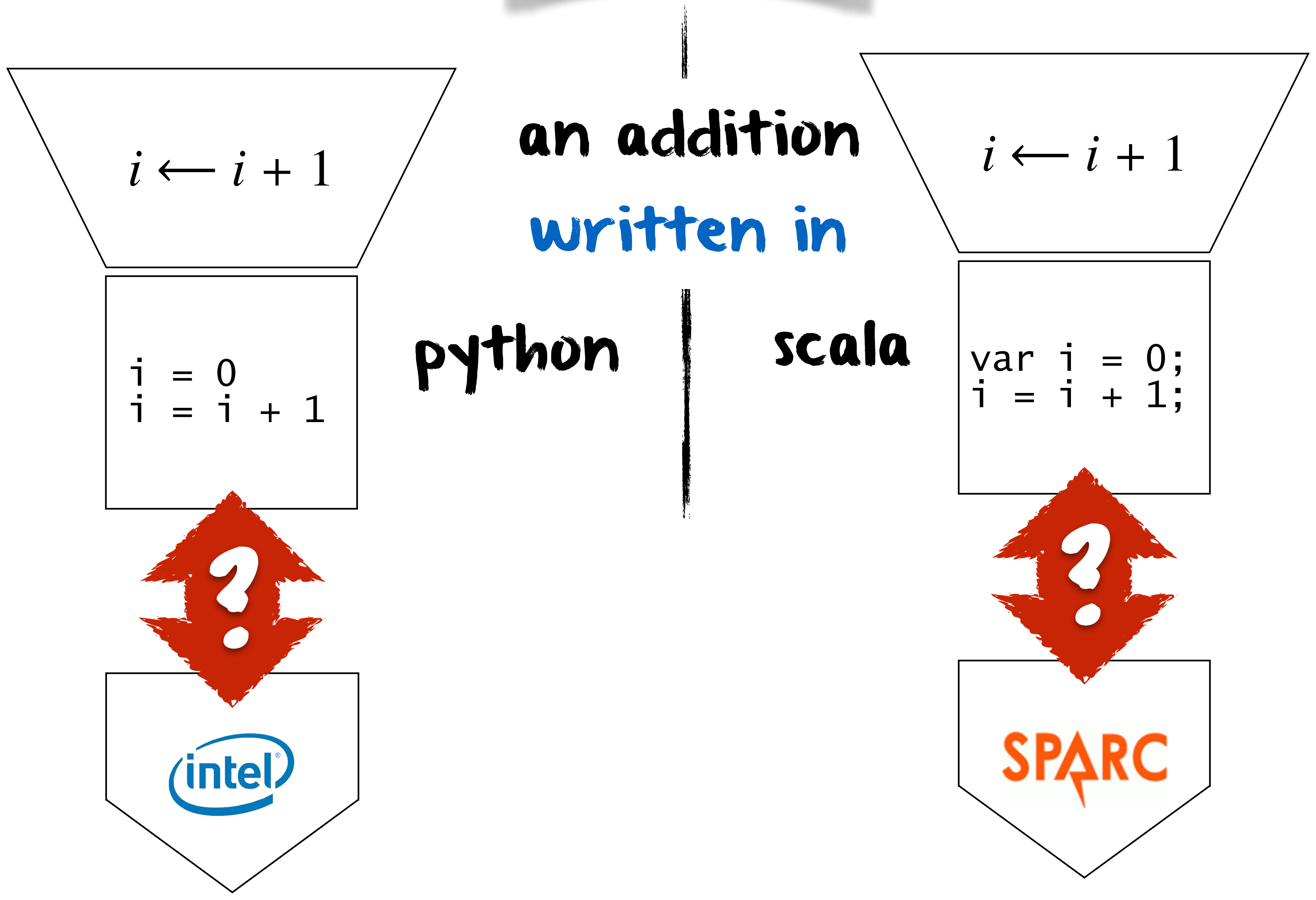
examples



```
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i = i + 1
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```
var i = 0;
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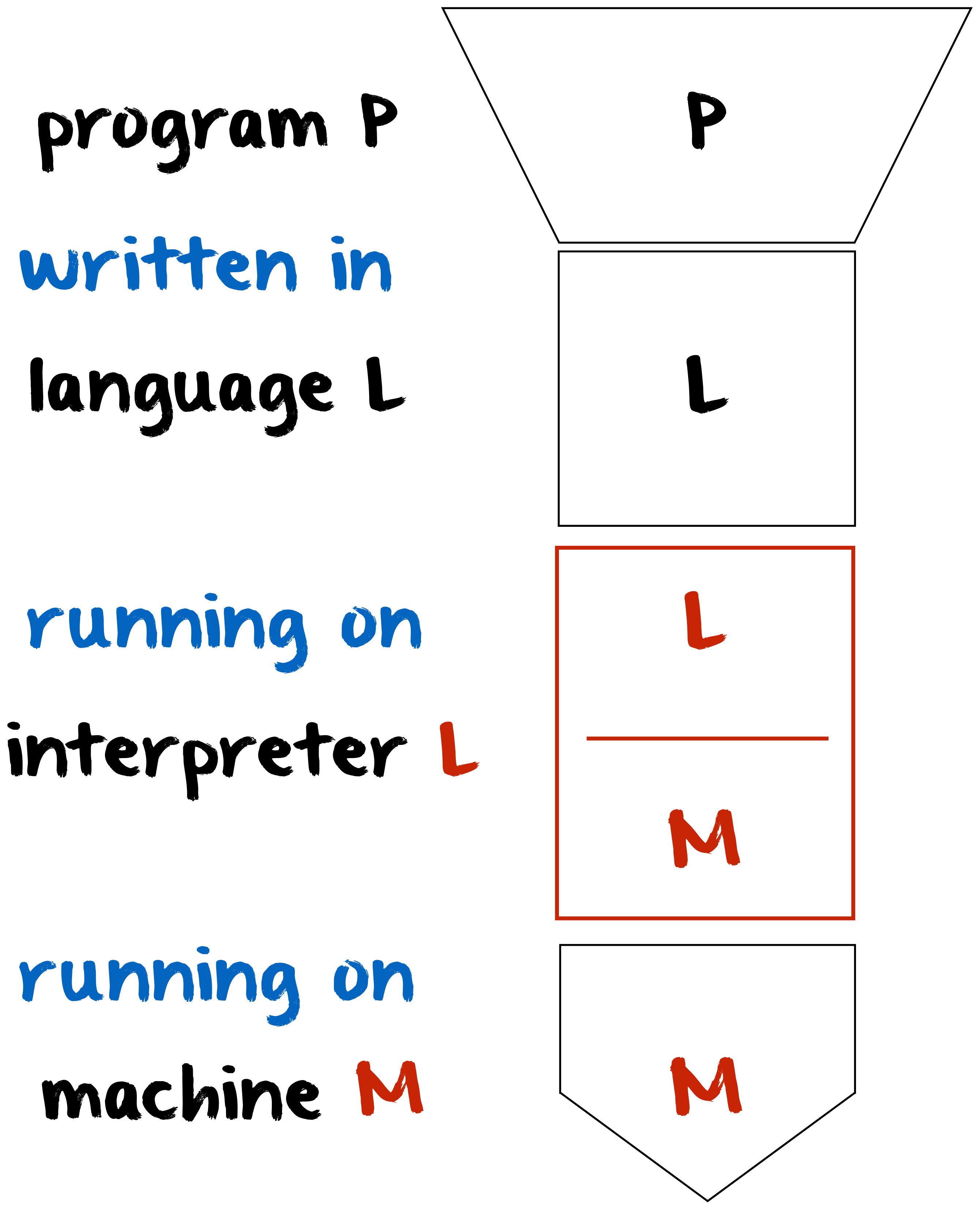
```

problem!

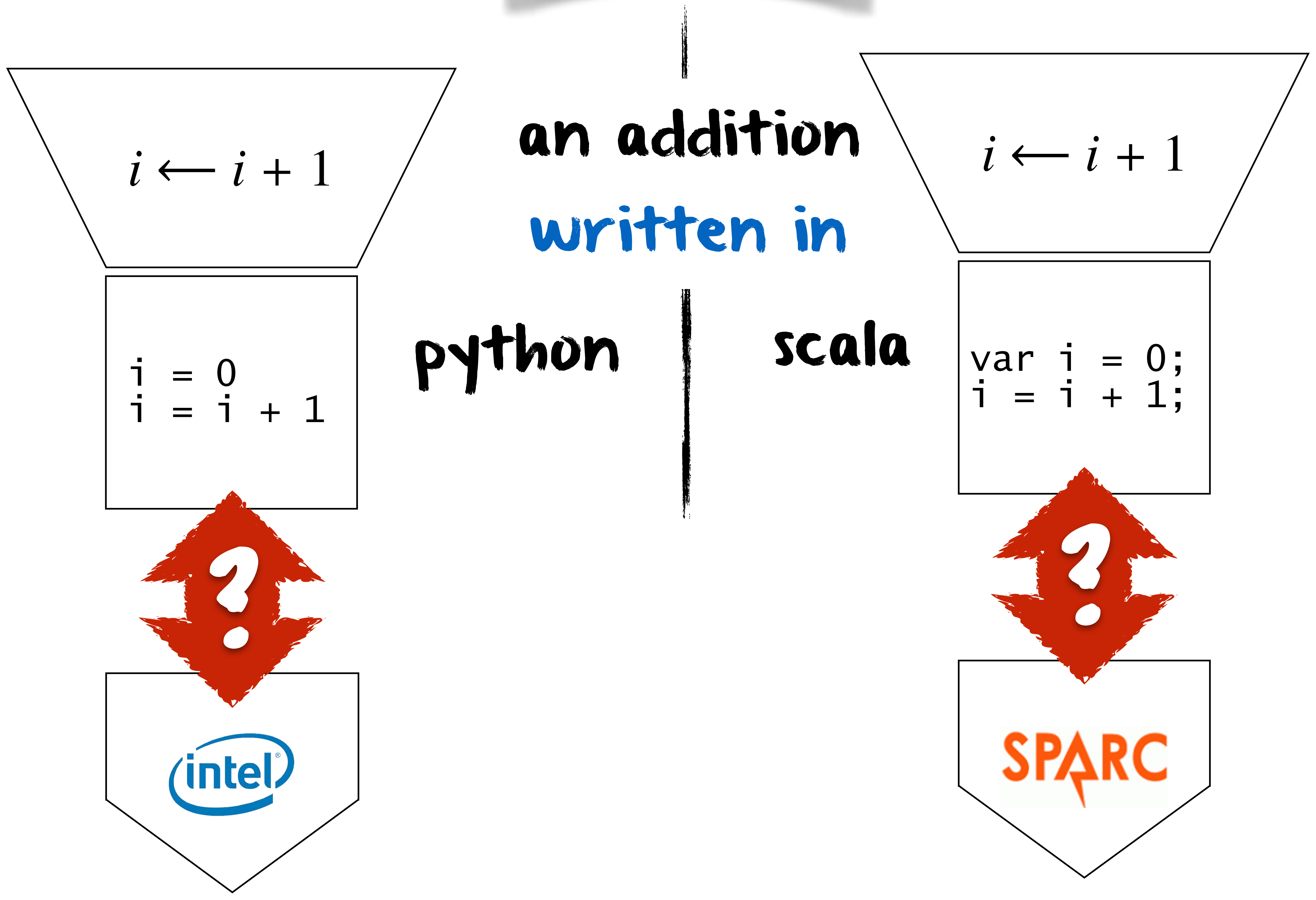
executions and interpreters

concept



an interpreter dynamically translates language L into language M

examples



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solution!

executions and interpreters

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program P

written in

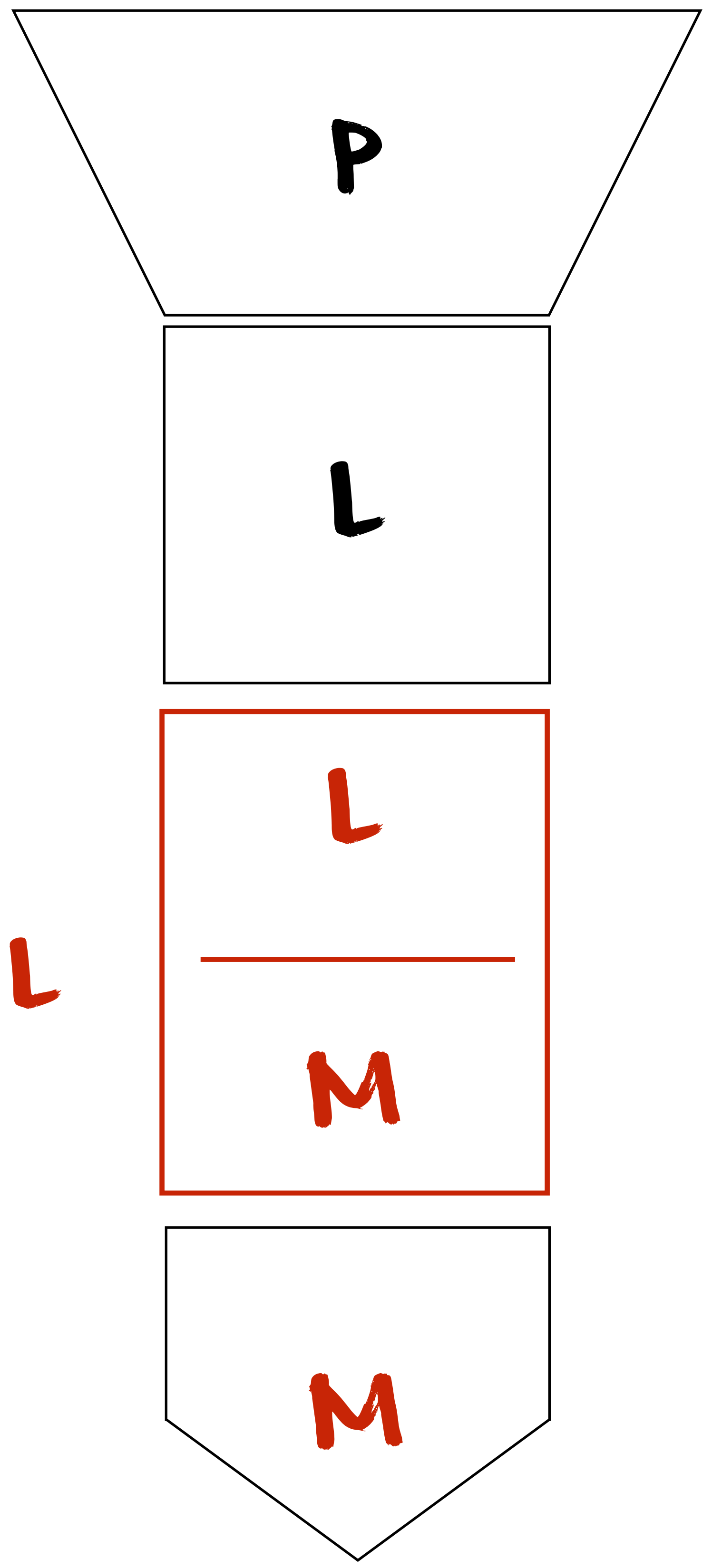
language L

running on

interpreter L

running on

machine M



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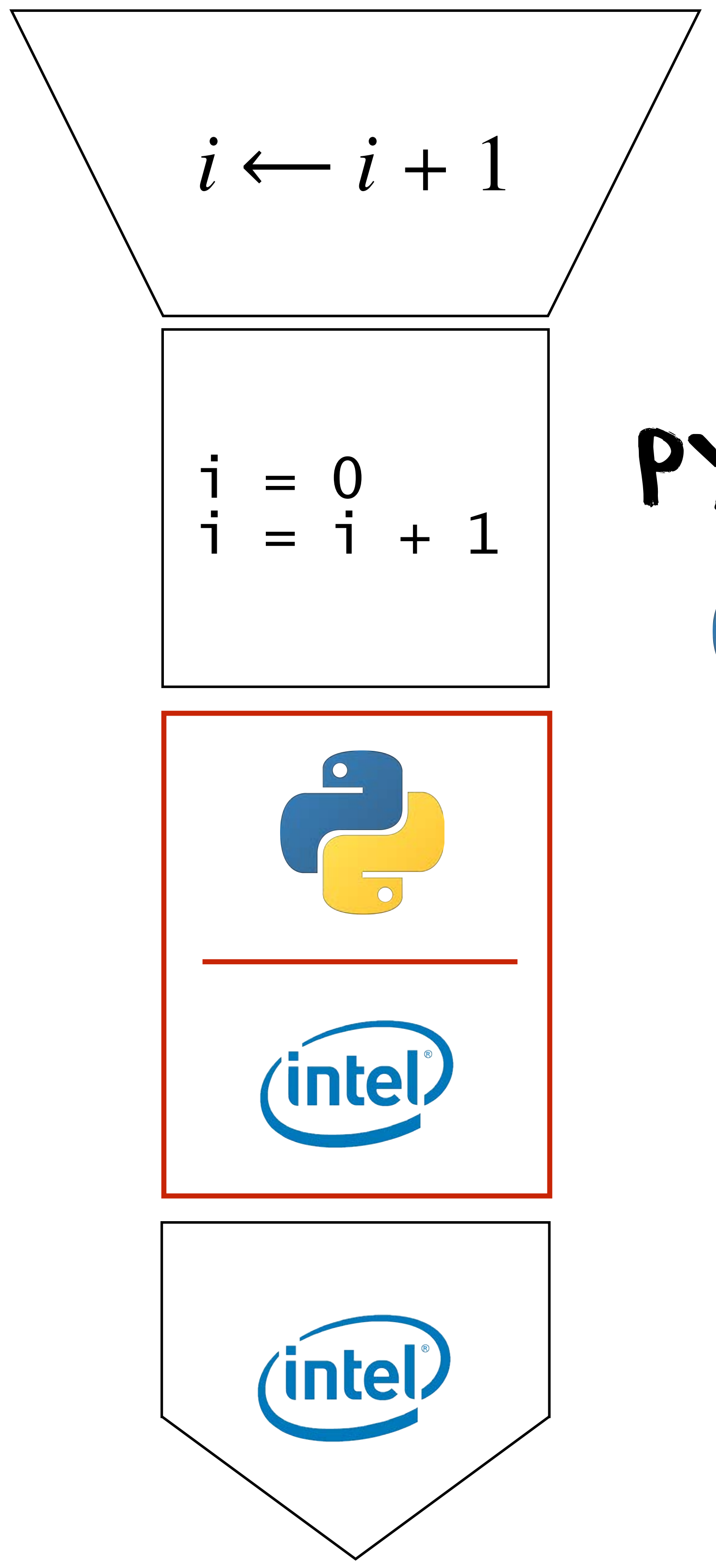

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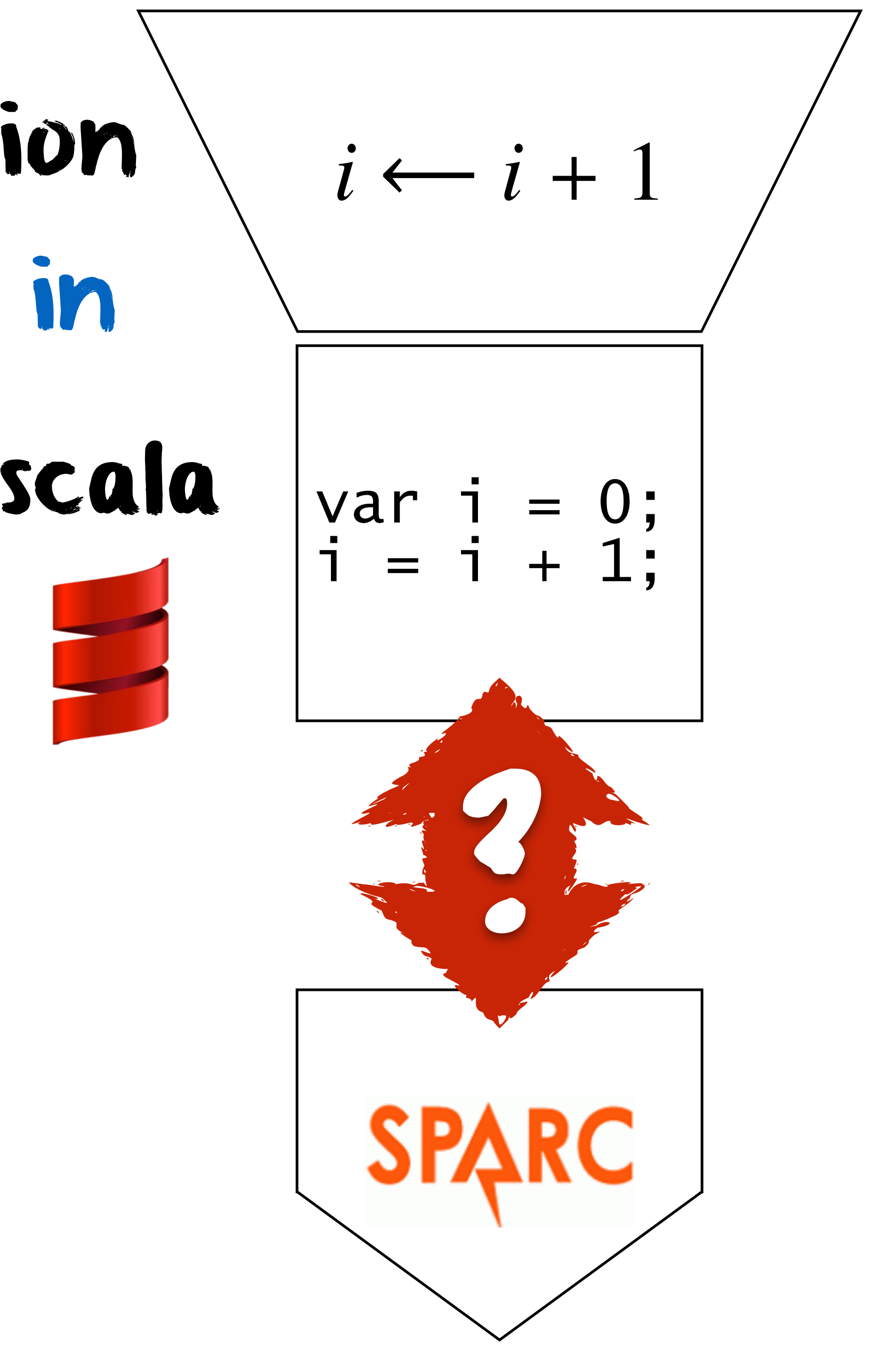
an addition

written in

python | scala



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executions and interpreters

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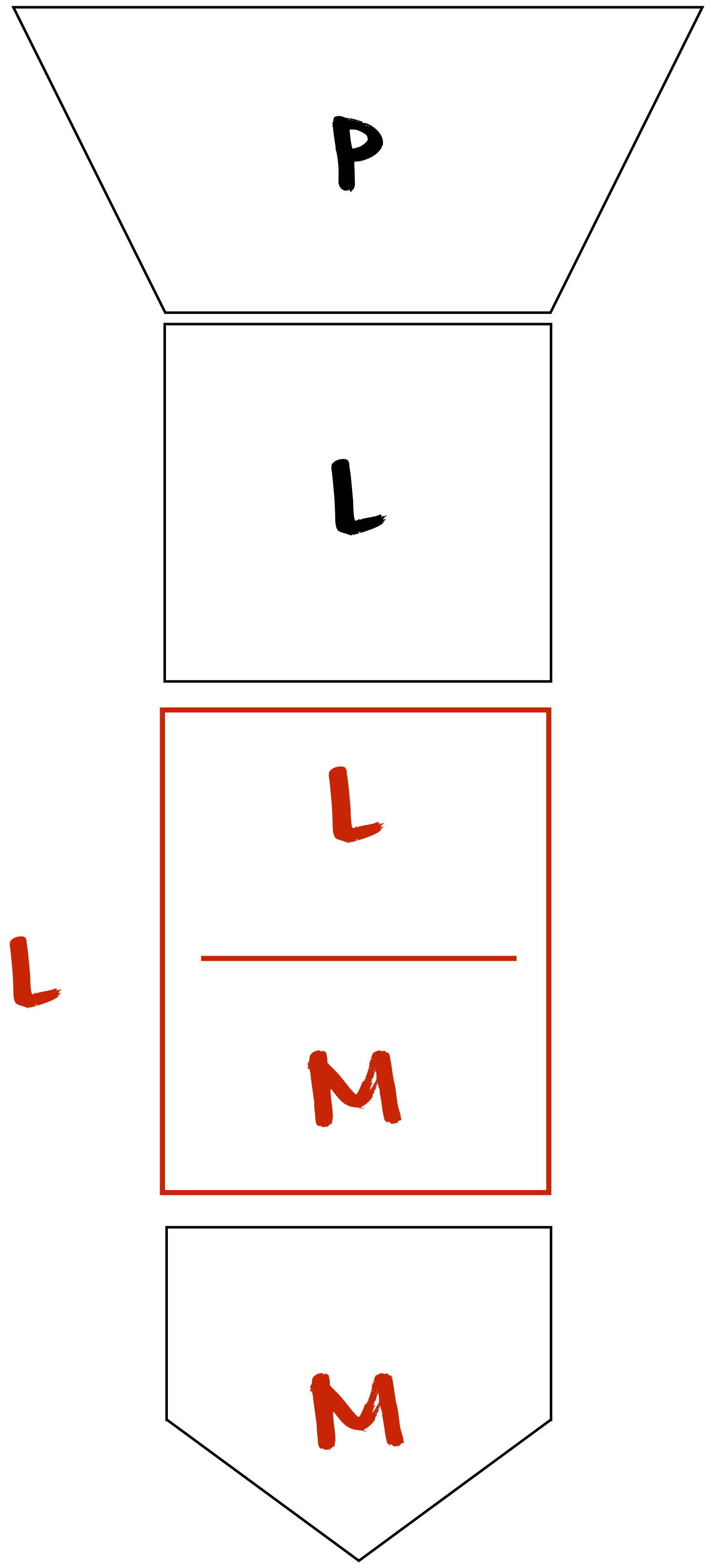

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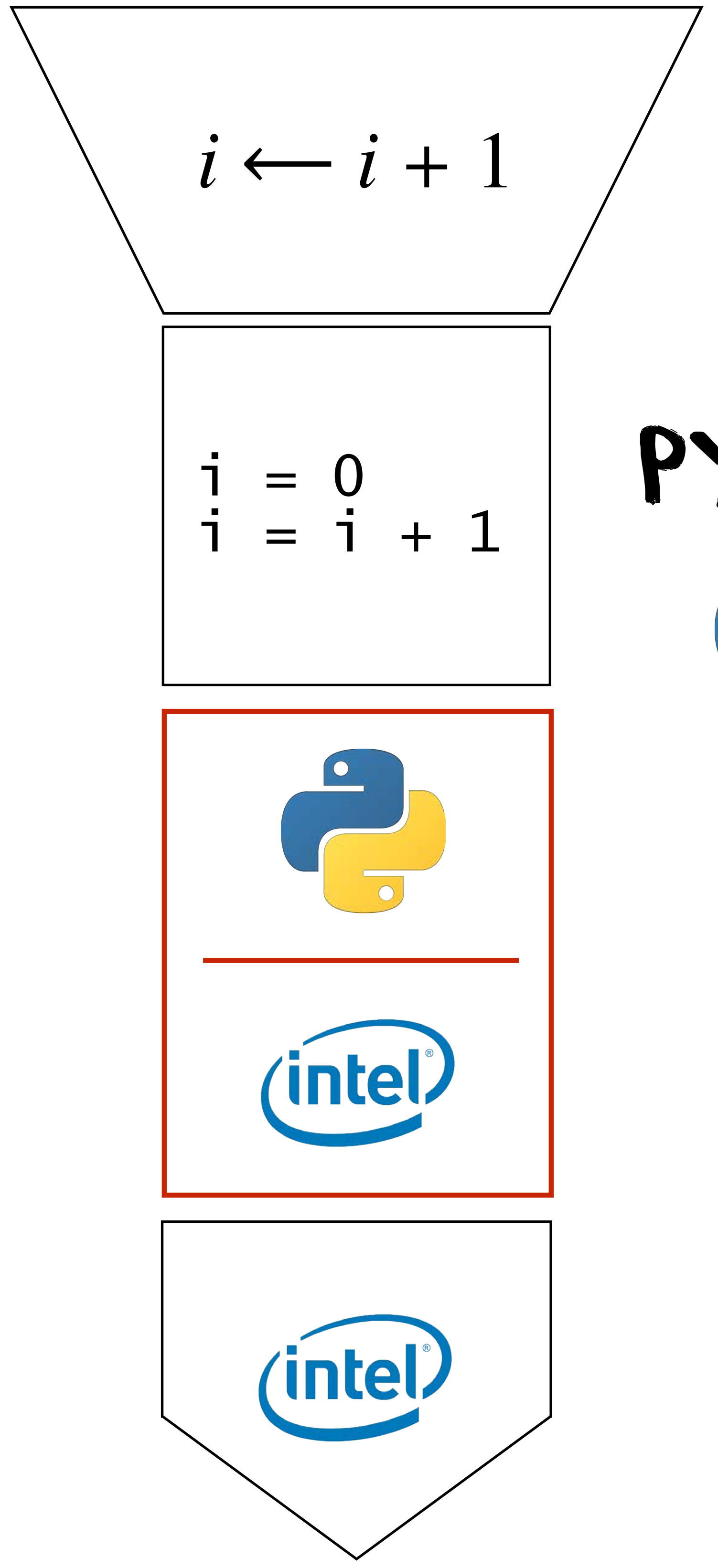

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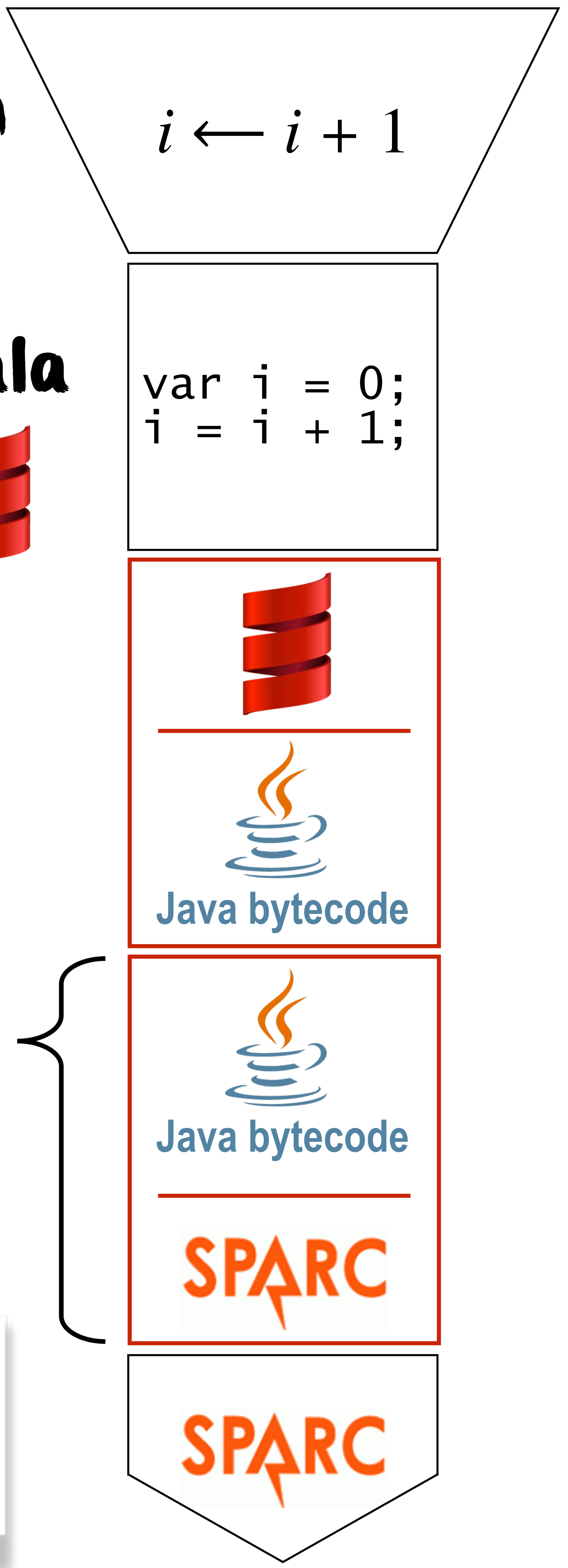

```
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```

java
virtual
machine

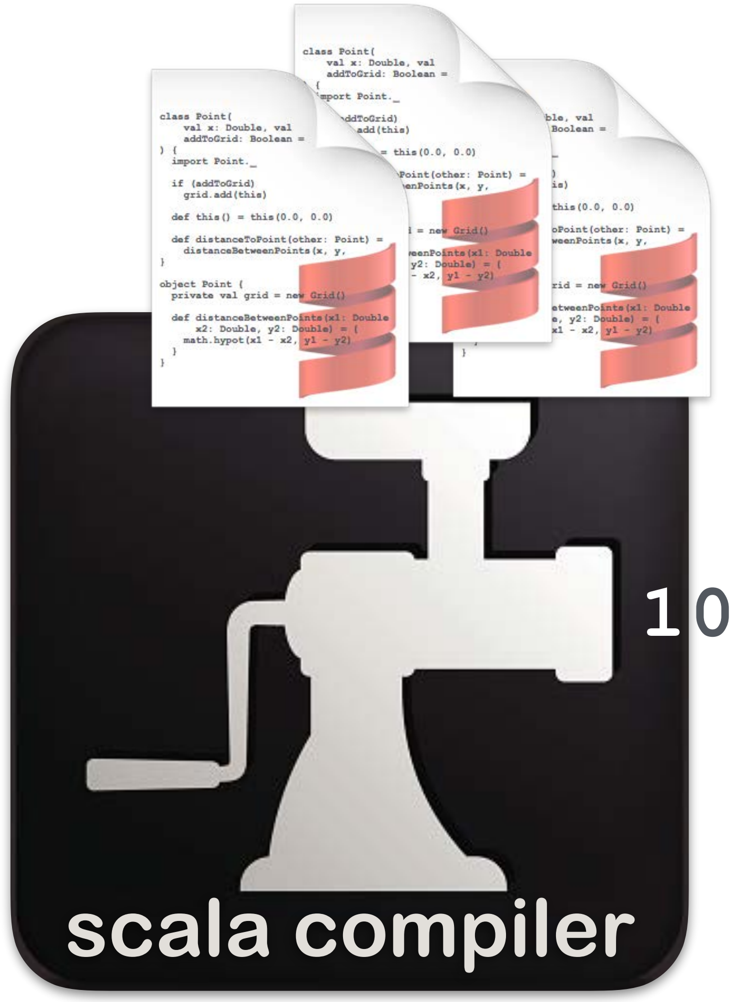
interpreter ⇔ emulator
⇔ virtual machine

what's a compiler

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

0010010100101011000100101011001101001110011111001101010...

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

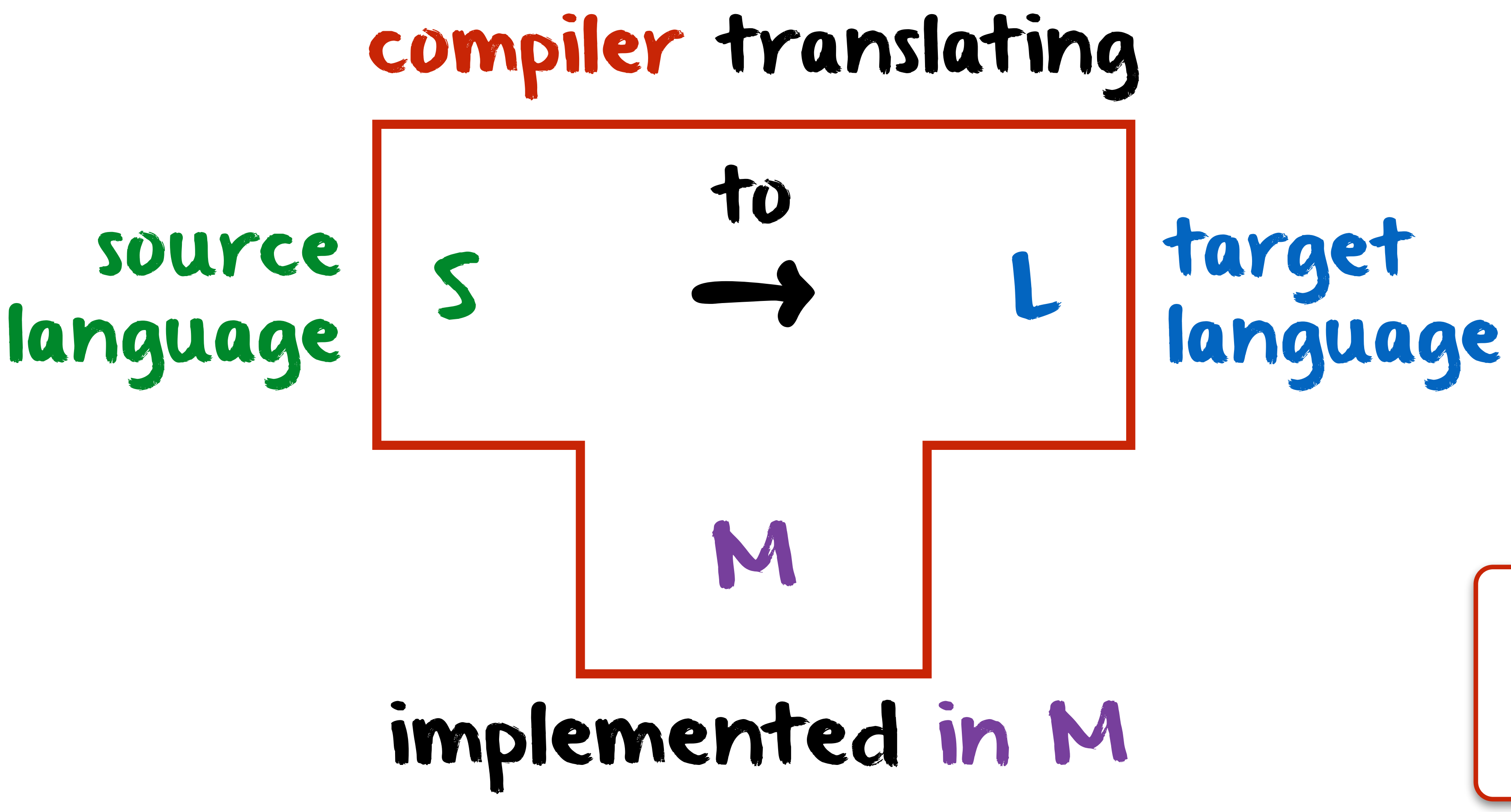


10011101100010010101100110100111001110011010...

what's a compiler

concept

examples



compiler translating

source language

S

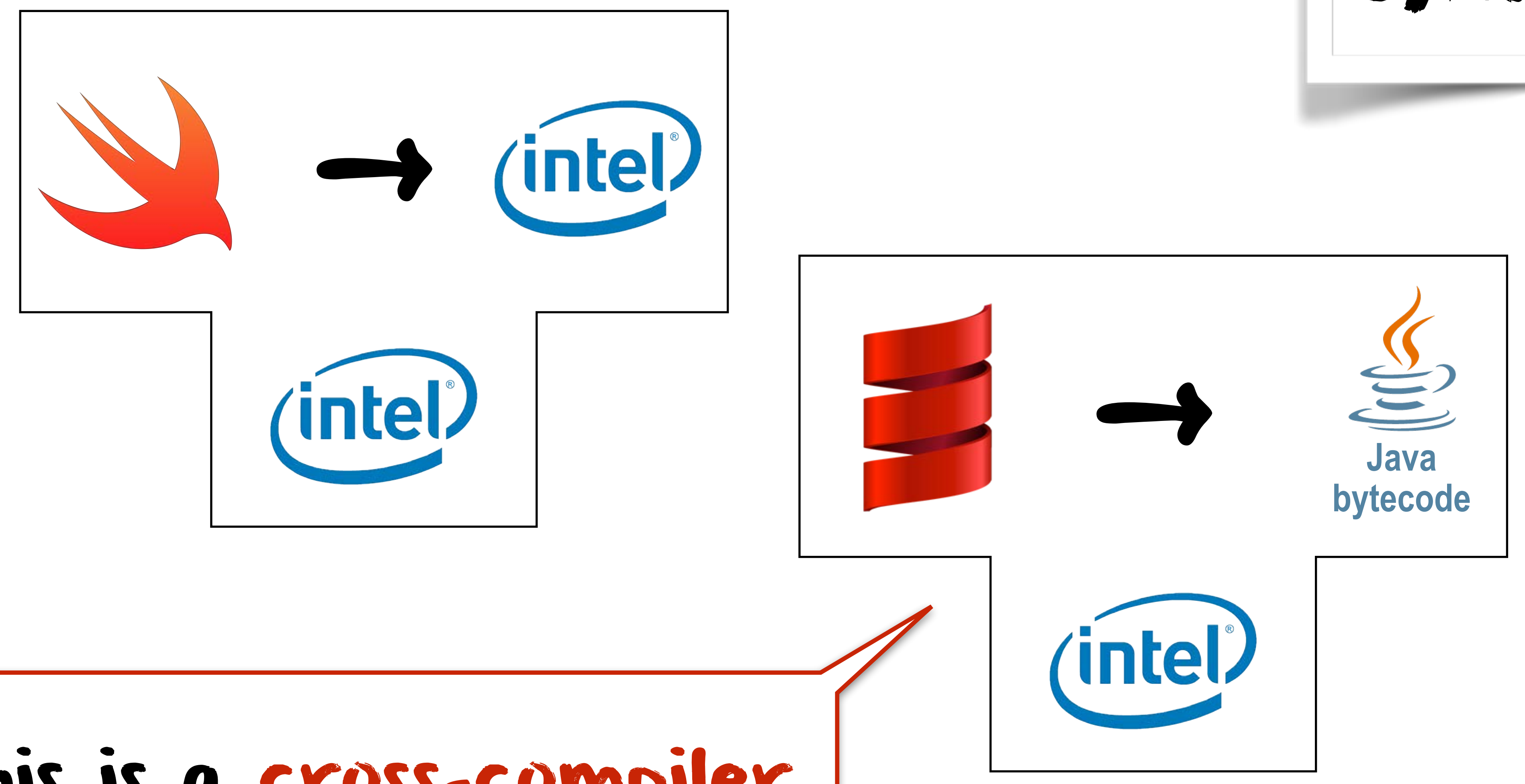
to

L

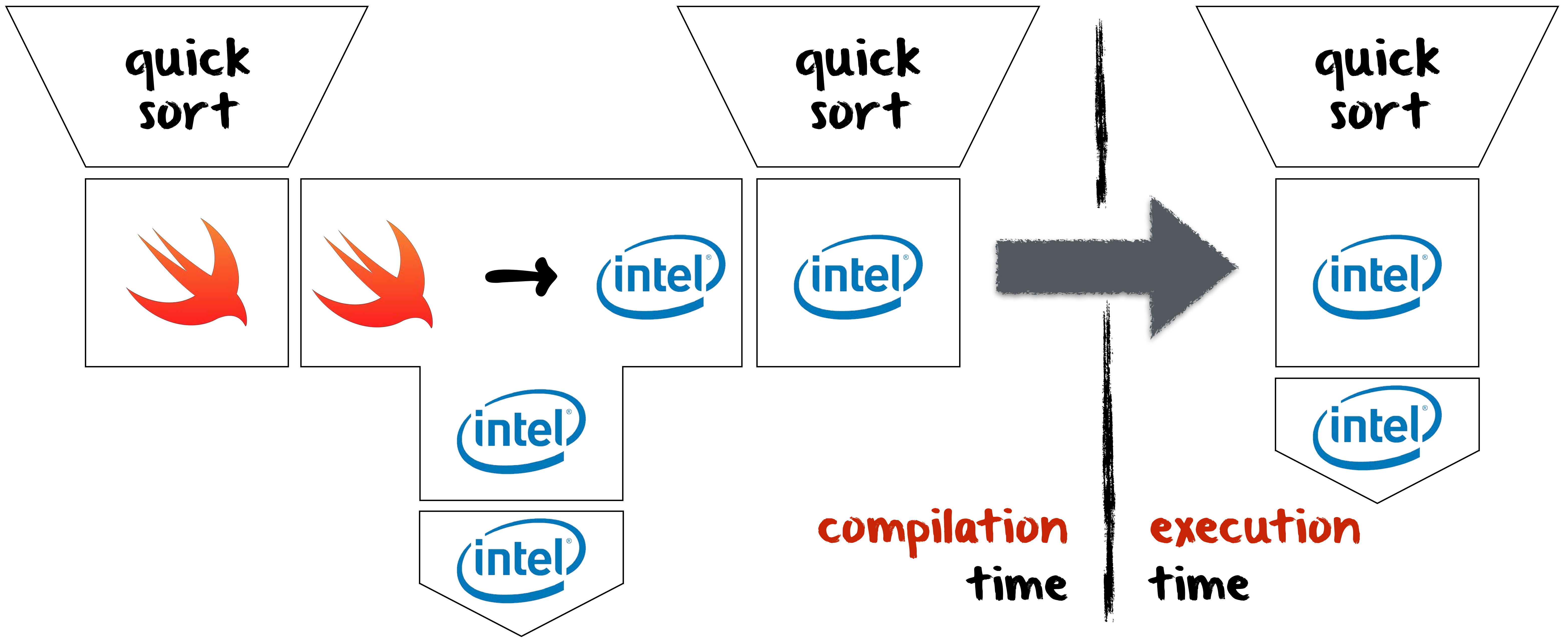
target language

M

implemented in M



this is a cross-compiler



quick sort

quick sort

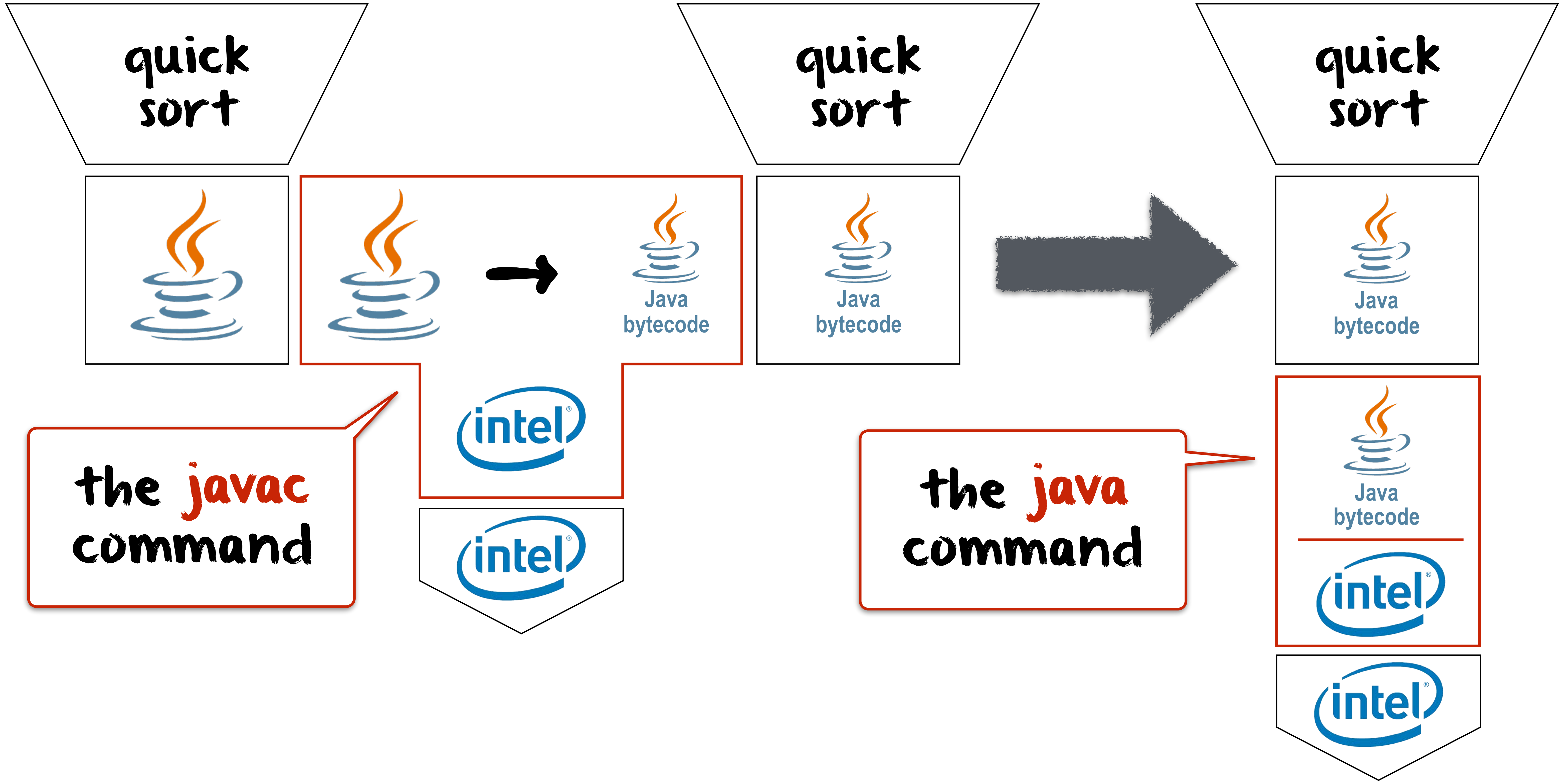
quick sort

compilation time

execution time

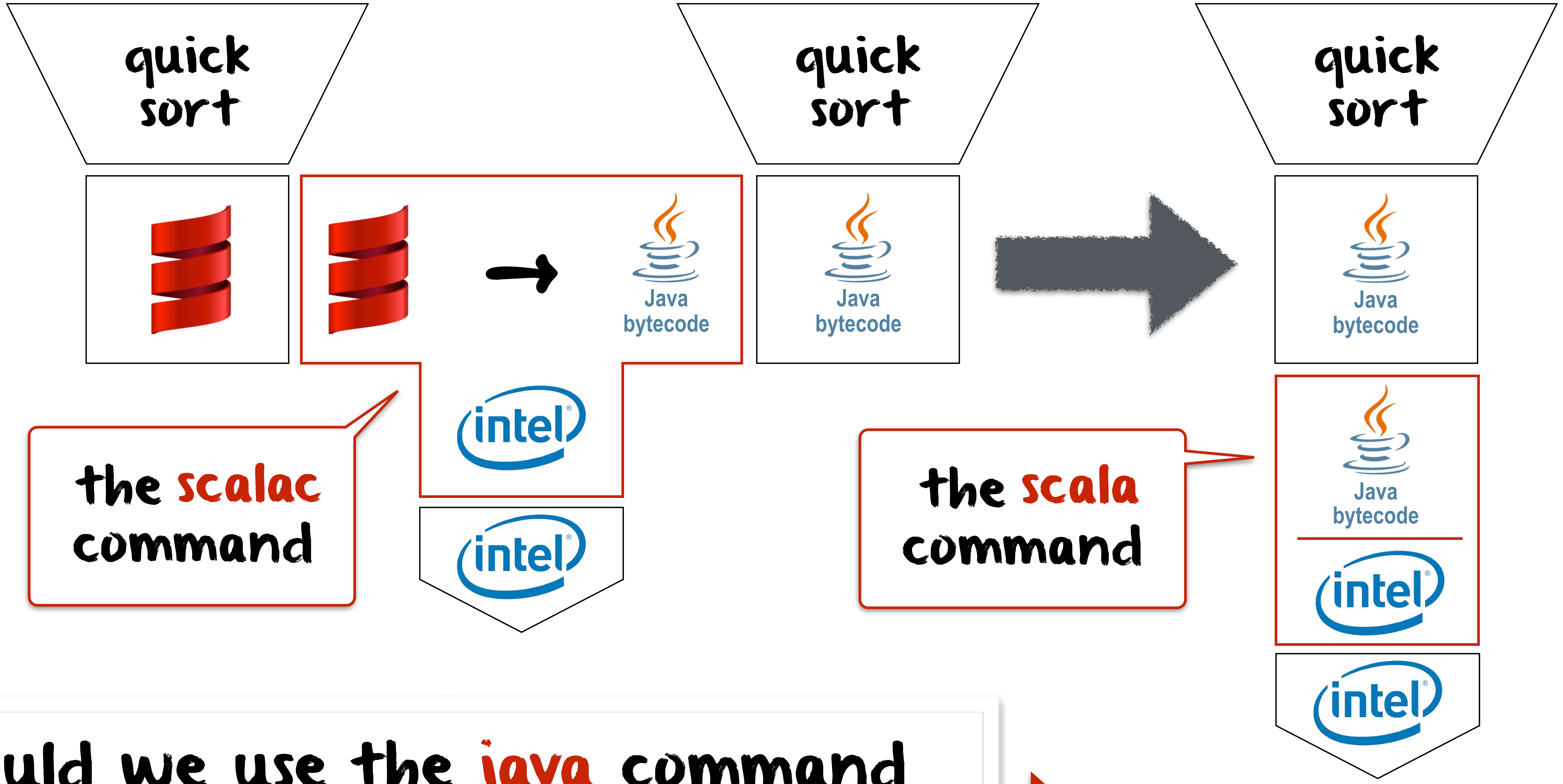
what's a compiler

the example of java



what's a compiler

the example of java



the scalac command

the scala command

Could we use the java command instead of the scala command?

no!

static vs. dynamic

TRANSLATION

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

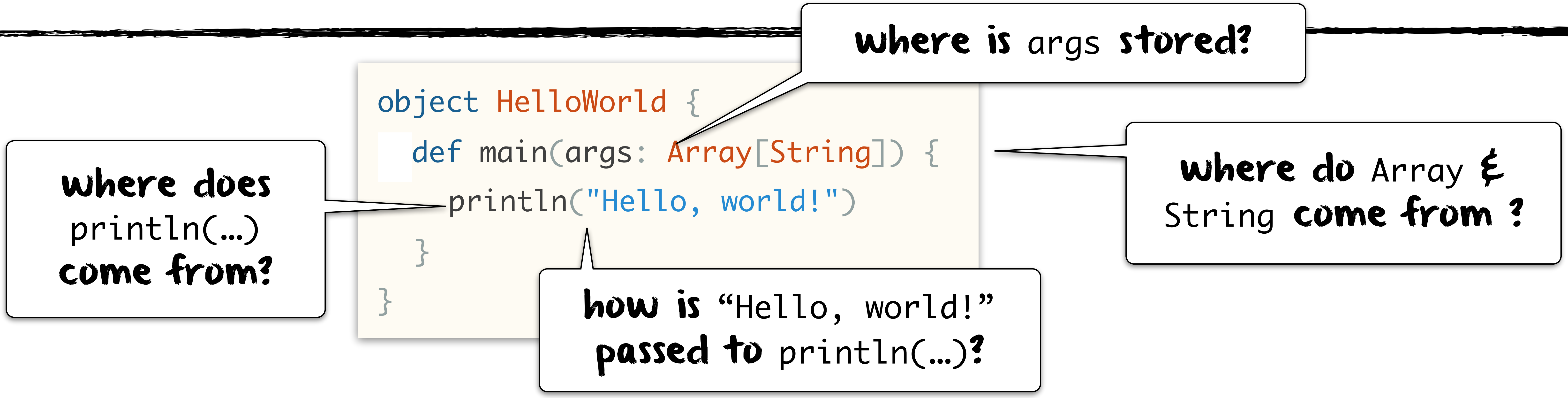
INTERPRETATION

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**



```
object HelloWorld {
  def main(args: Array[String]) {
    println("Hello, world!")
  }
}
```

where is args stored?

where does println(…) come from?

where do Array & String come from ?

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

what are runtime systems & libraries?

```
object HelloWorld {
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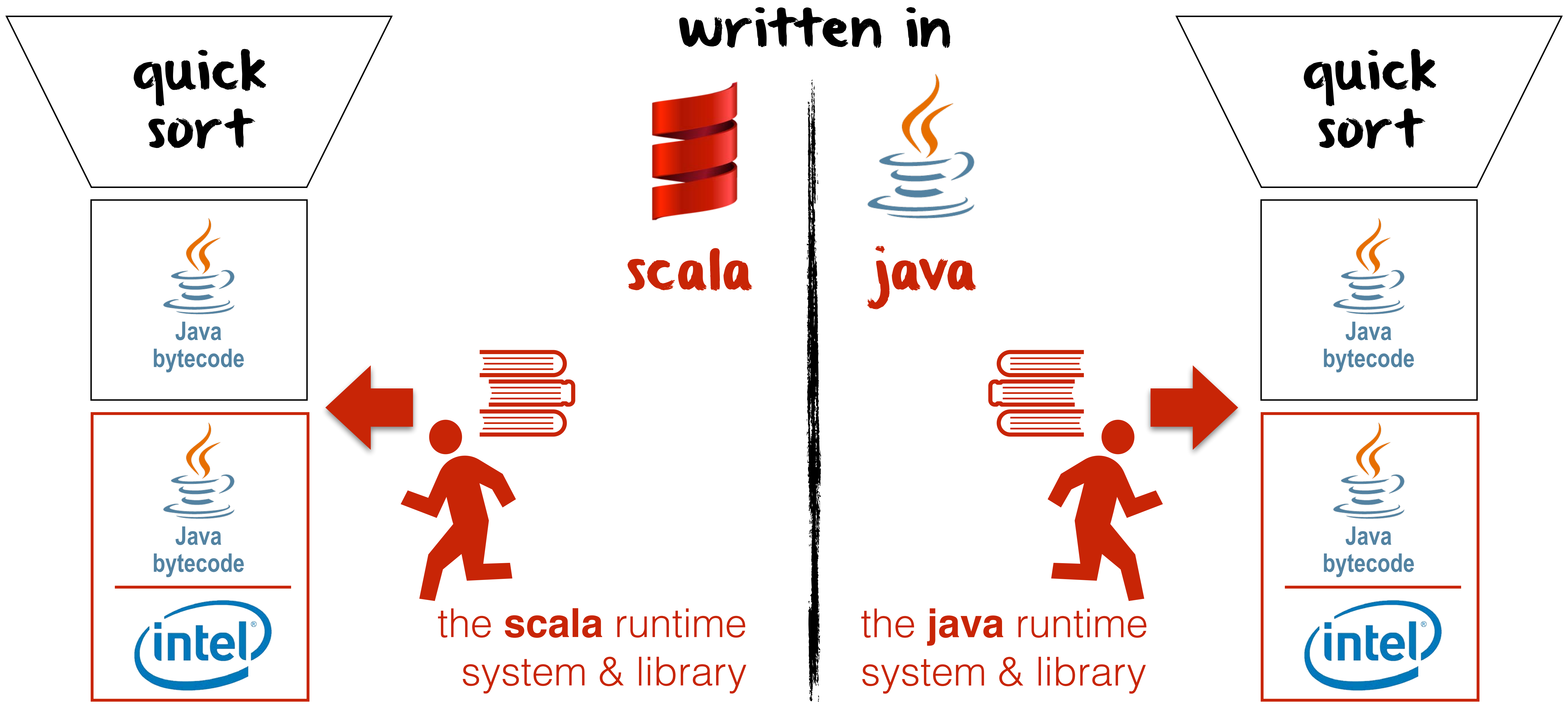


written in

scala

java

the **scala** runtime system & library

the **java** runtime system & library

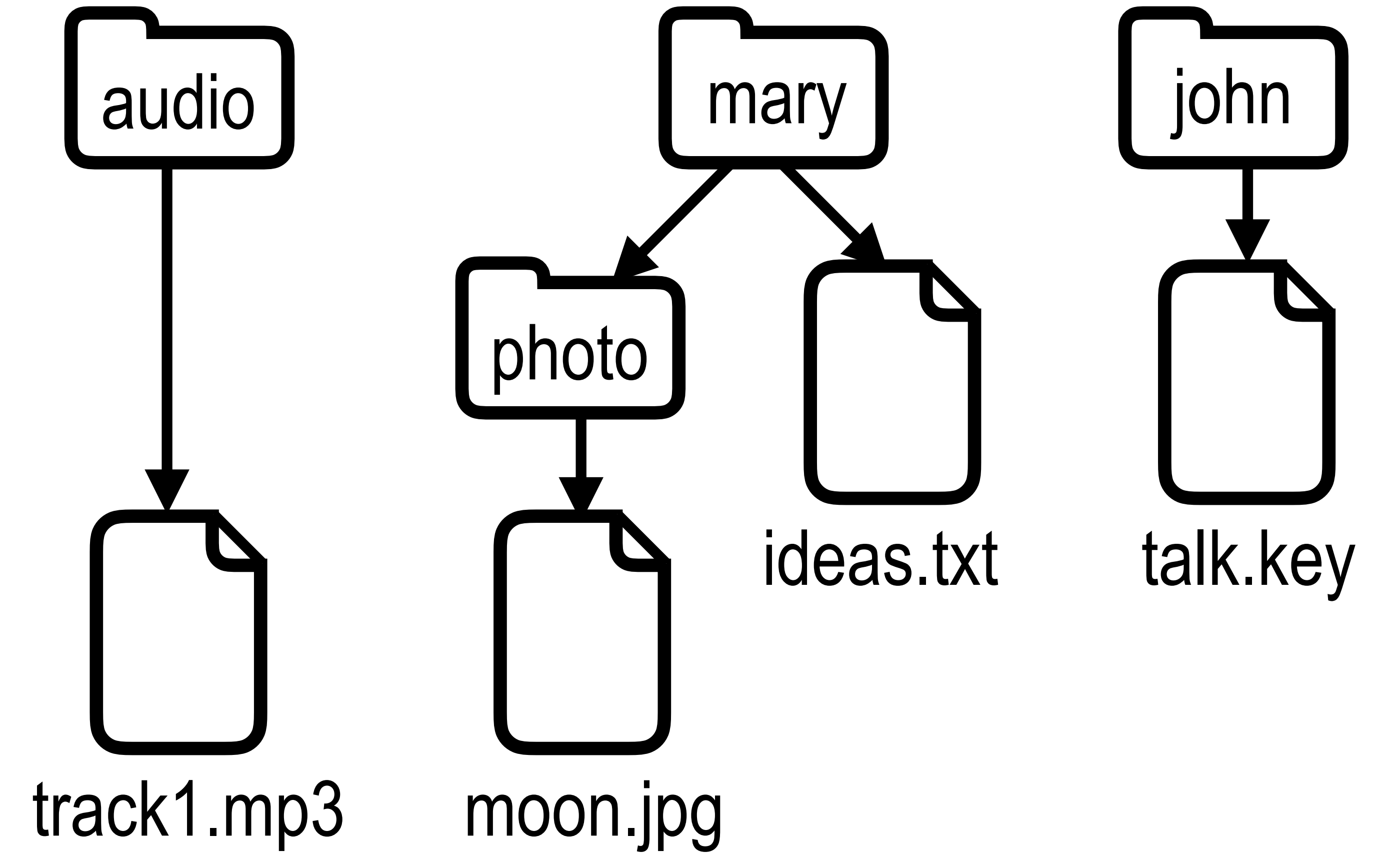
filesystems & command shells

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



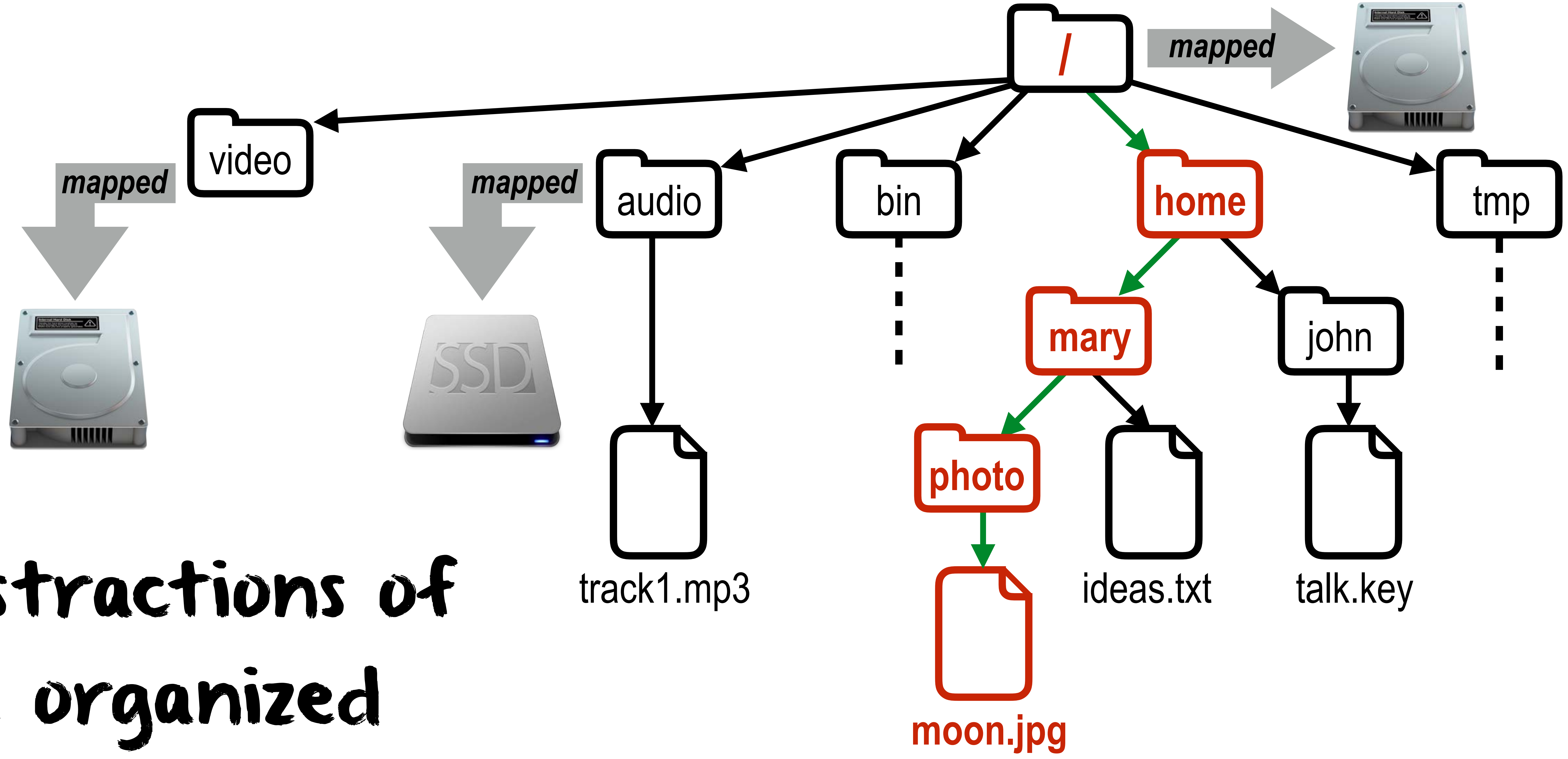
a filesystem is based on the abstractions of files and directories, which are organized and accessed via paths in a namespace

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



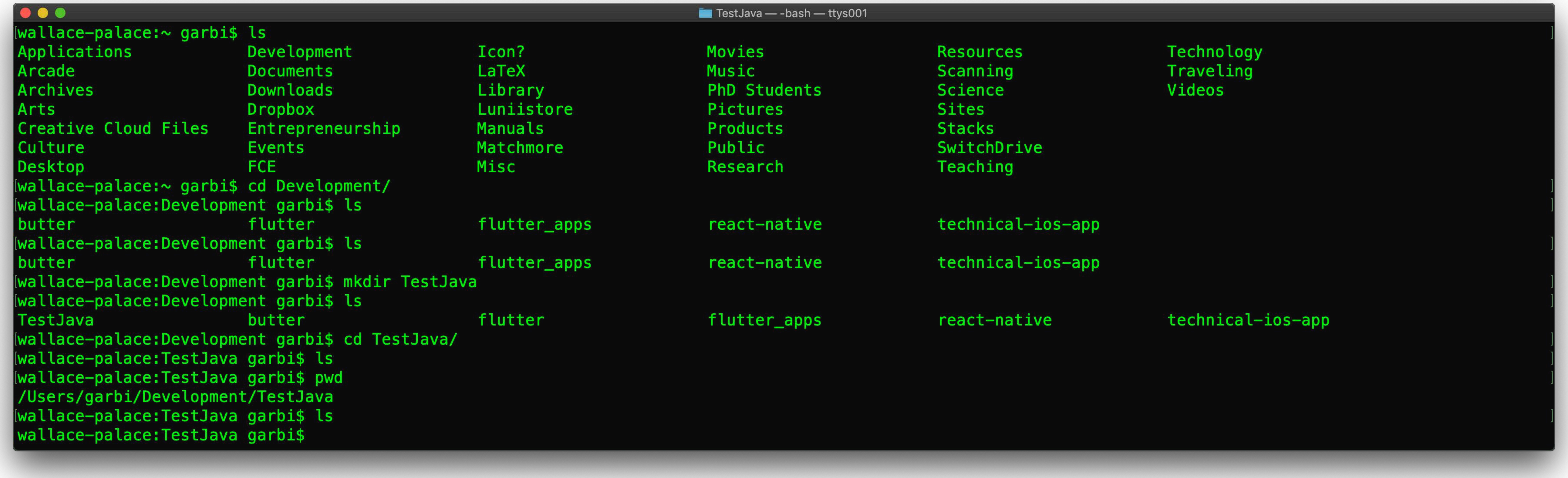
path: /home/mary/photo/moon.jpg

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

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



```
wallace-palace:~ garbi$ ls
Applications            Development             Icon?                   Movies                  Resources               Technology
Arcade                  Documents               LaTeX                   Music                   Scanning                Traveling
Archives                Downloads               Library                 PhD Students            Science                 Videos
Arts                    Dropbox                 Luniistore              Pictures                Sites
Creative Cloud Files    Entrepreneurship        Manuals                 Products                Stacks
Culture                 Events                  Matchmore               Public                  SwitchDrive
Desktop                 FCE                     Misc                    Research                Teaching
wallace-palace:~ garbi$ cd Development/
wallace-palace:Development garbi$ ls
butter                  flutter                 flutter_apps            react-native            technical-ios-app
wallace-palace:Development garbi$ ls
butter                  flutter                 flutter_apps            react-native            technical-ios-app
wallace-palace:Development garbi$ mkdir TestJava
wallace-palace:Development garbi$ ls
TestJava                butter                  flutter                 flutter_apps            react-native            technical-ios-app
wallace-palace:Development garbi$ cd TestJava/
wallace-palace:TestJava garbi$ ls
wallace-palace:TestJava garbi$ pwd
/Users/garbi/Development/TestJava
wallace-palace:TestJava garbi$ ls
wallace-palace:TestJava garbi$
```

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*