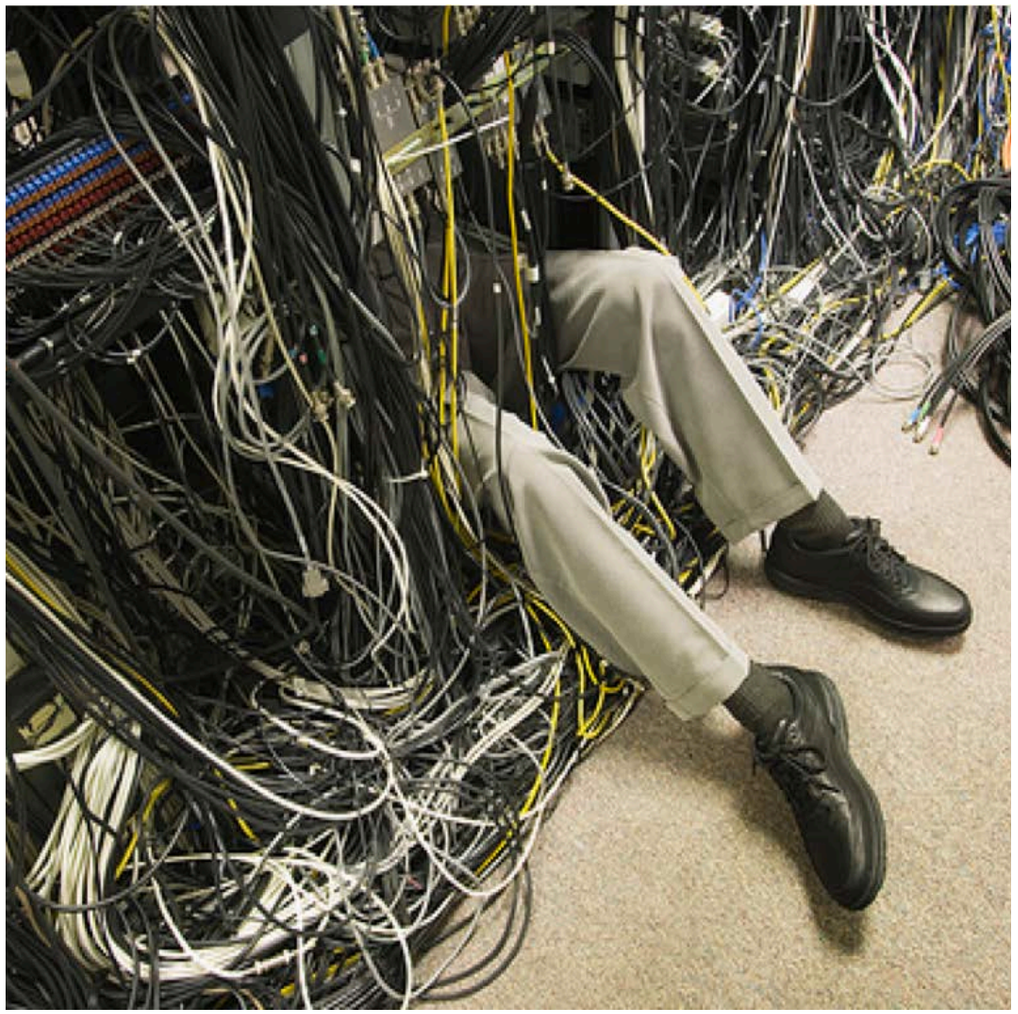
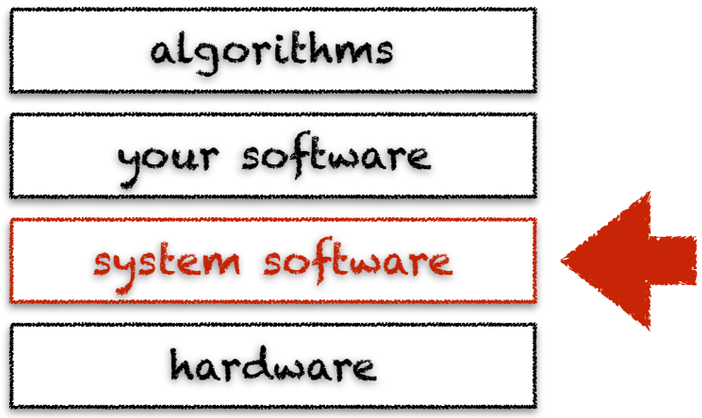
# system software



# 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

# examples of system software

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

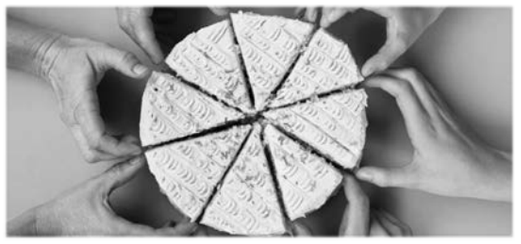
# bits of history

1940s
1950s ◆ no system software

1960s ◆ batch systems

the
waiting era

1970s ◆ multi-user & time-sharing



the
sharing era

1980s ◆ personal desktop computers

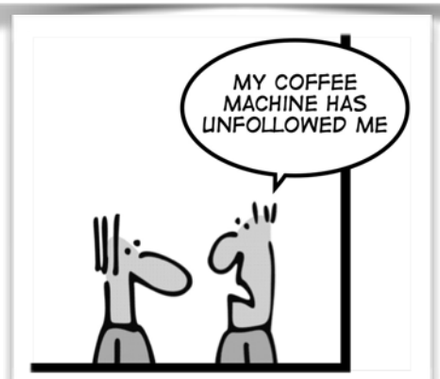
the
personal era

1990s ◆ distributed systems

the
communication era

2000s ◆ mobile systems

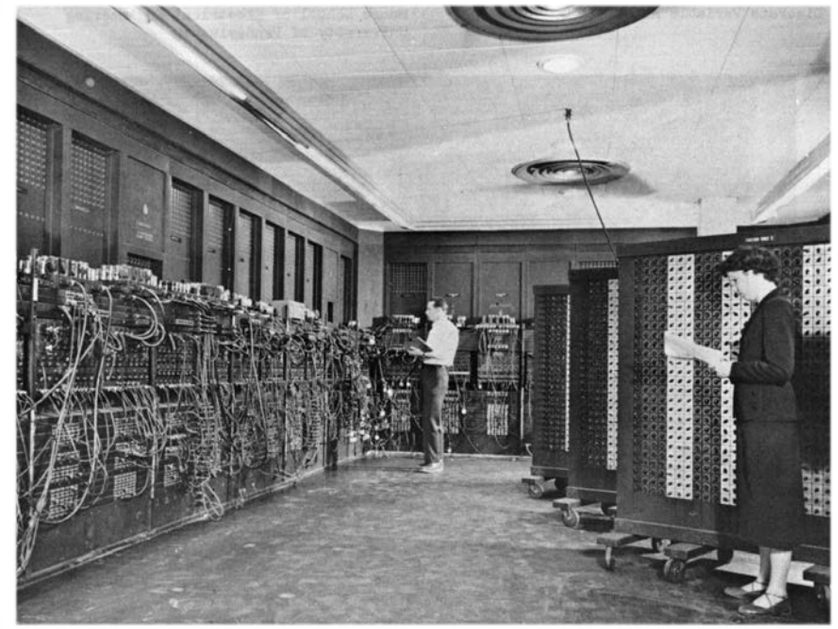
2010s ◆ ubiquitous systems




the digital
transformation era

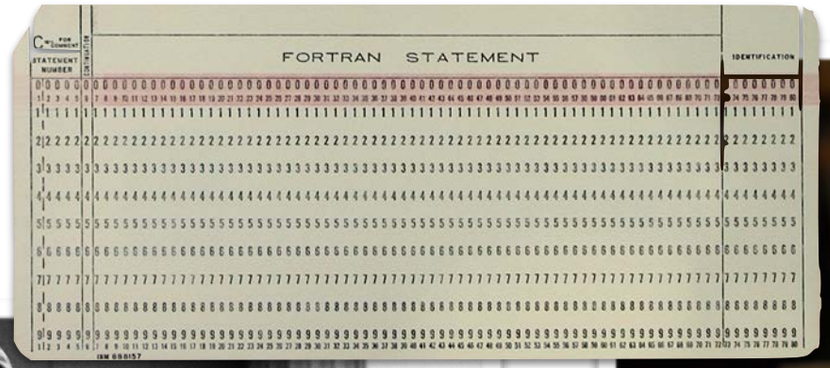
# no systems software

- 1940s: programming based on dials & switches

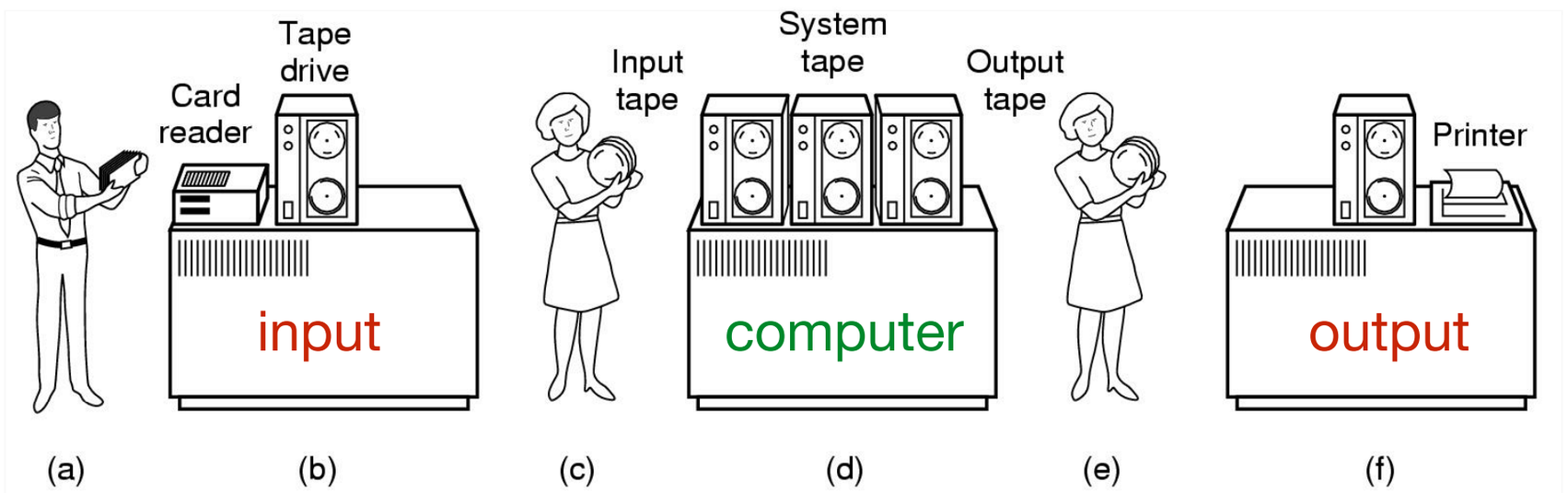


ENIAC: 30 tons, 200 kilowatts

- 1950s: single user, punched cards, paper tape

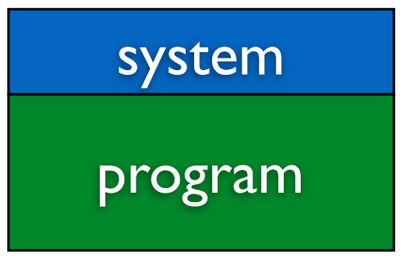



# 1960s batch systems

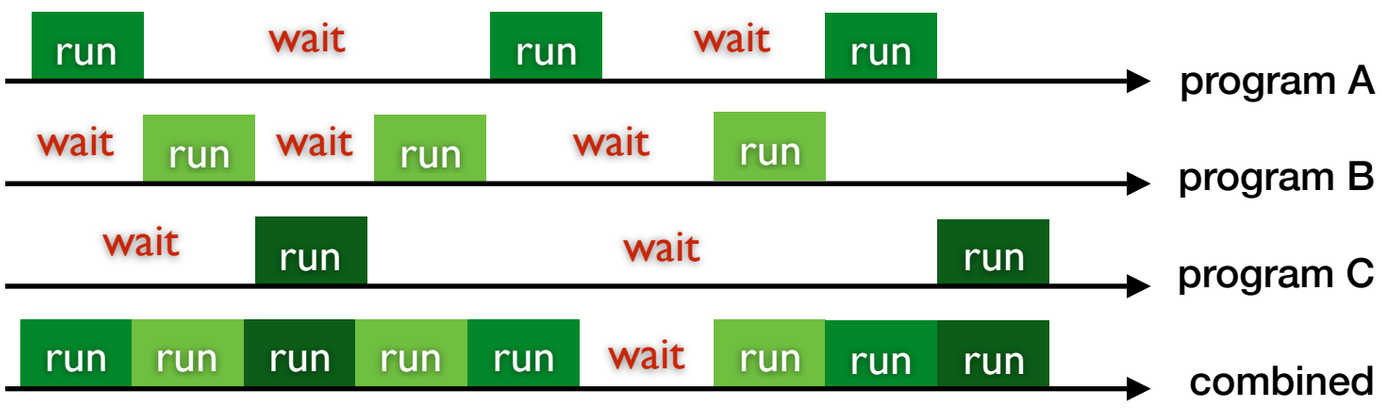


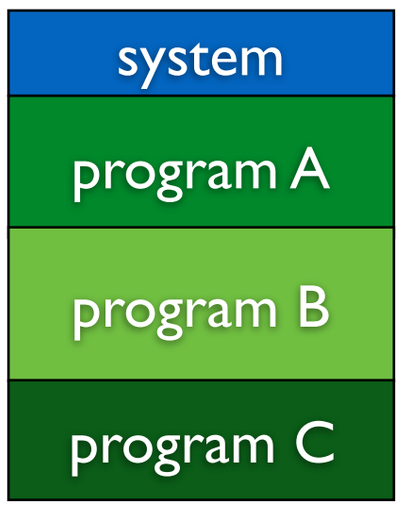

(a) put cards into reader
(b) read cards to tape
(c) put input tape on computer
(d) perform the computation
(e) put output tape on printer
(f) print output tape on paper

## first uni-programmed batch systems

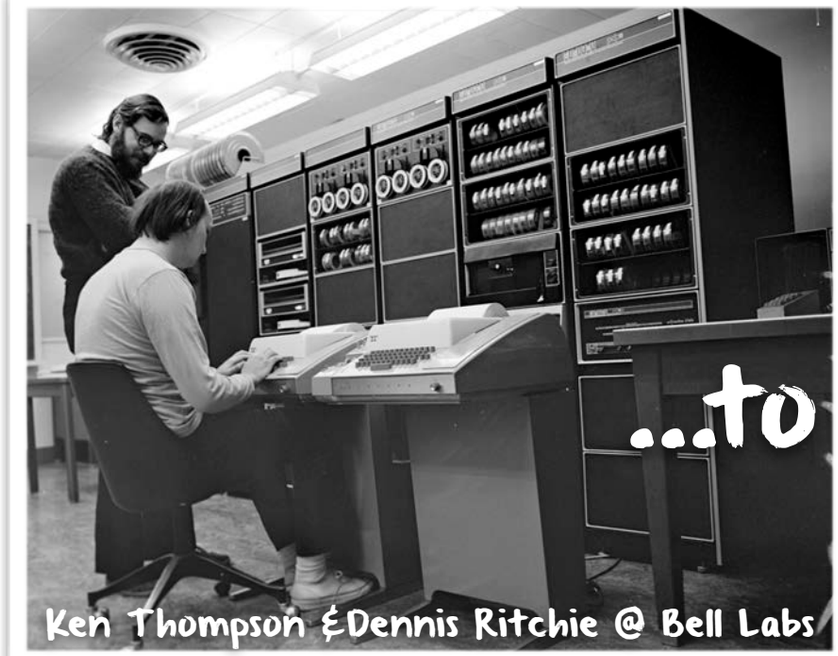

## then multi-programmed batch systems



# 1970s multi-user & time-sharing

from Multics...



Ken Thompson & Dennis Ritchie @ Bell Labs

...to Unix

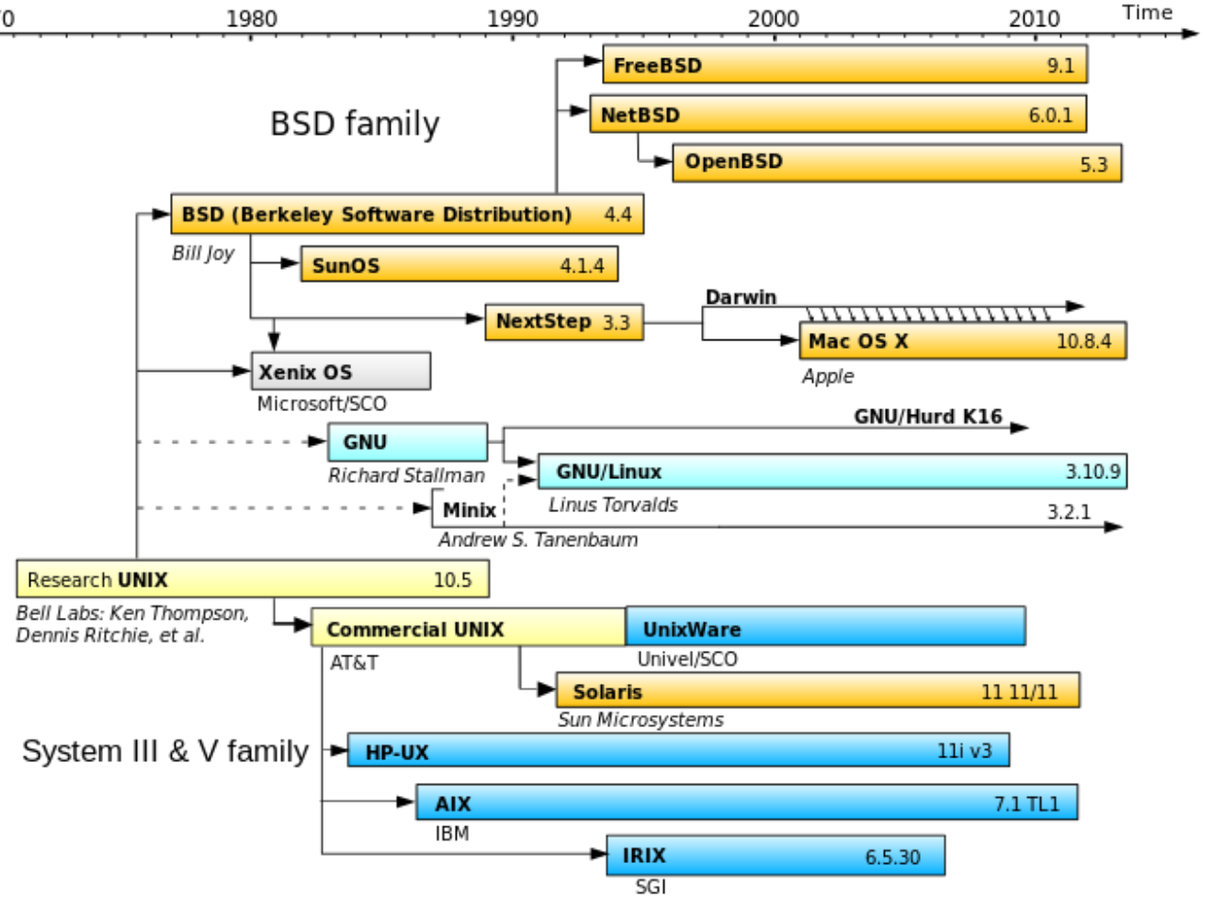
- 1960s: disasters... but great learning & innovations
  - OS/360: years behind schedule, shipped with 1000 known bugs
  - Multics: started in 1963, working in 1969, far too complex
- 1970s: finally mastering complexity thanks to:
  - higher level structured languages (Algol, C, Pascal, etc.)
  - portable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

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

# microprocessors & Moore's law

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

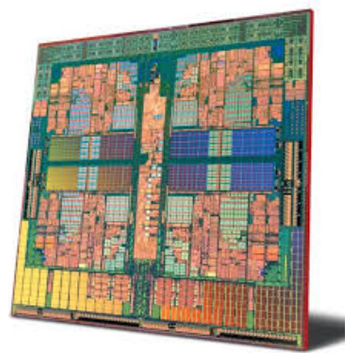
**the number of transistors** in a dense integrated circuit **doubles approximately every two years**

- 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**

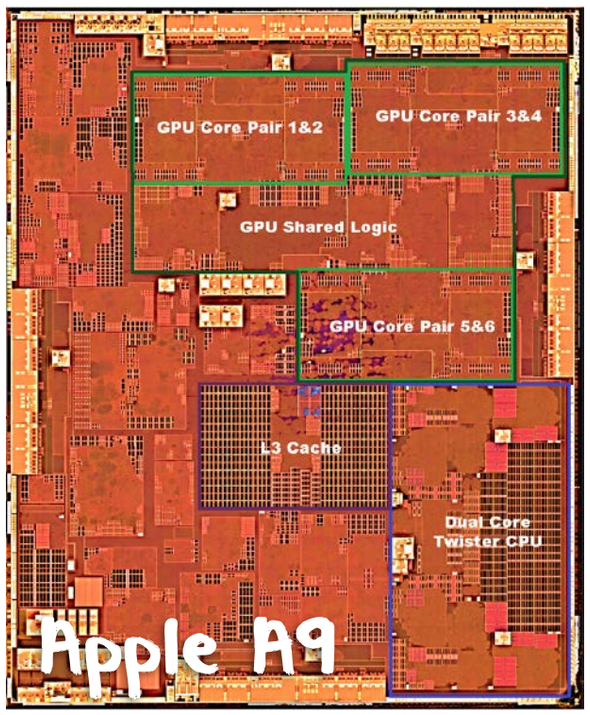
# writing system software is about mastering exponential complexity

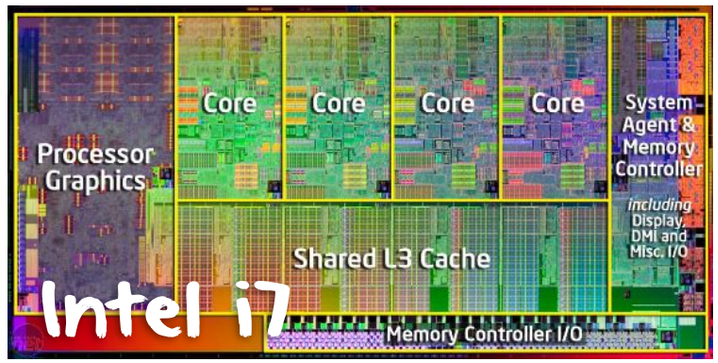
As long as there were no machines, programming was no problem at all; when we had a few weak computers, programming became a mild problem and now that we have gigantic computers, programming has become an equally gigantic problem. In this sense the electronic industry has not solved a single problem,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

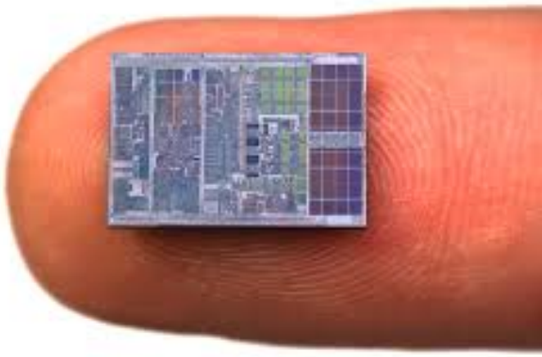
Edgster Dijkstra, The Humble Programmer. Communication of the ACM, vol. 15, no. 10. October 1972. Turing Award Lecture.



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

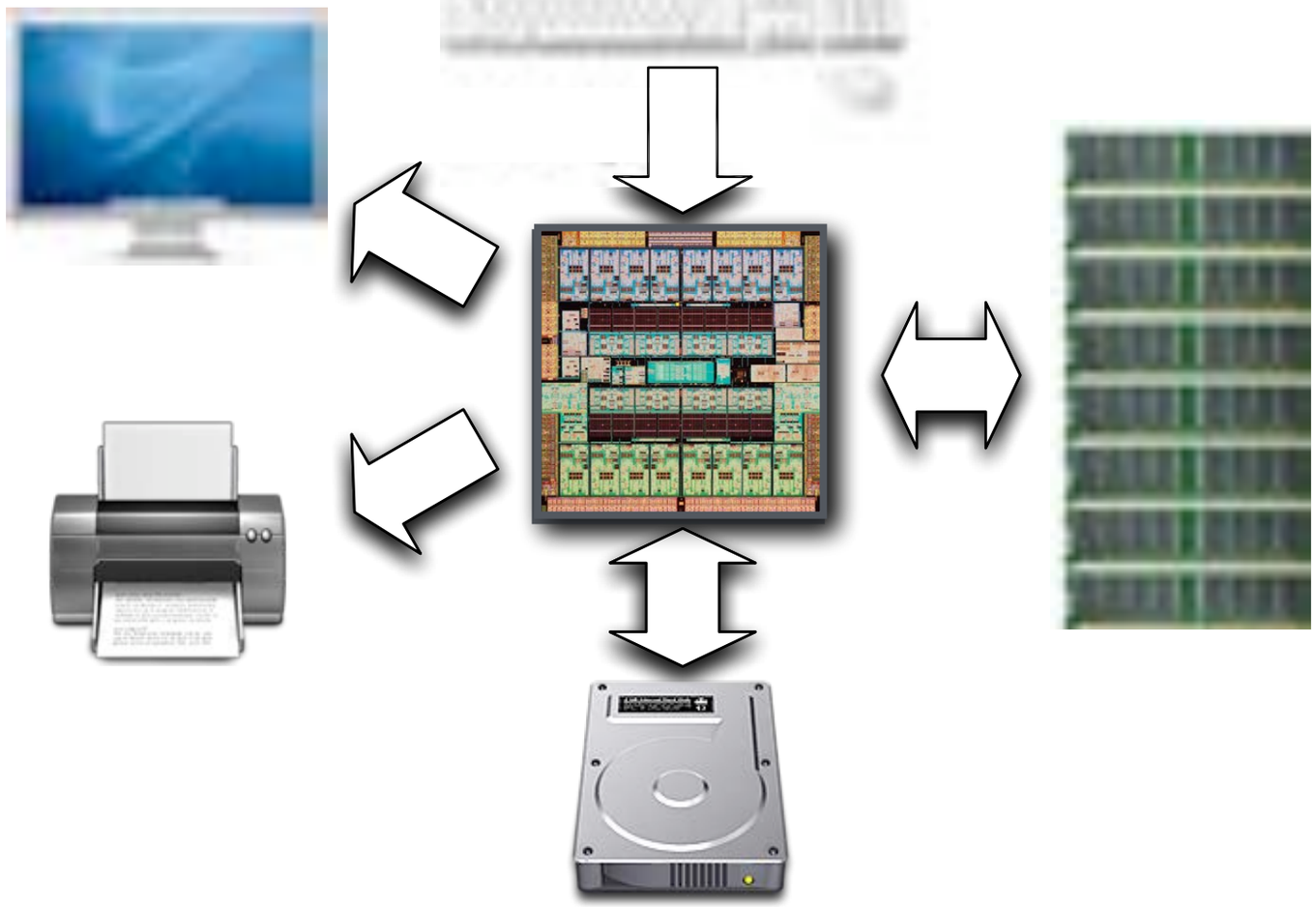
## 2000s: my phone is my computer

- smartphones & tablets as computers
- generalization of wireless networks

## 2010s: everything is a computer

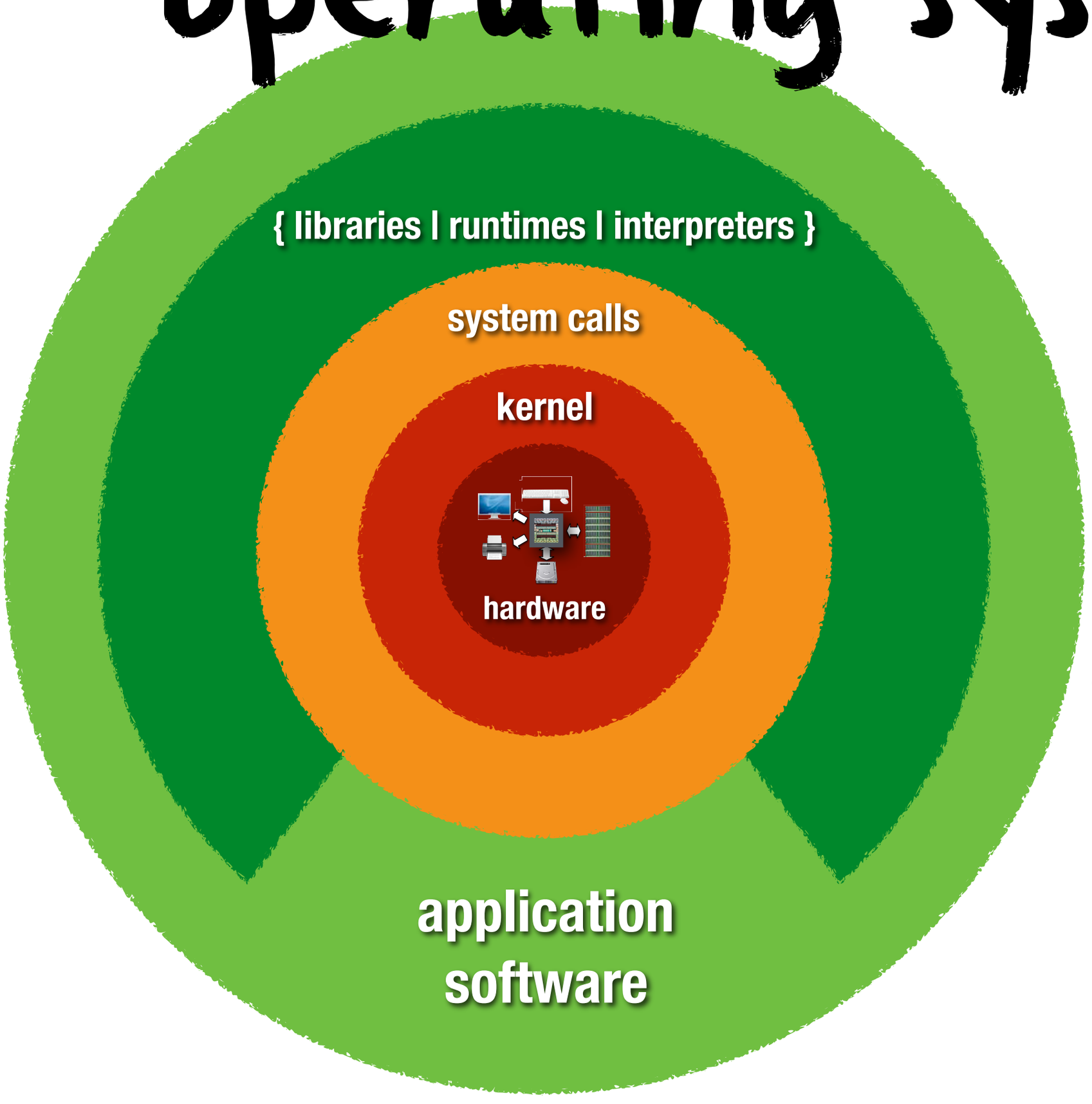
- smart objects & the Internet of things
- personal networks connected to the cloud

# operating system



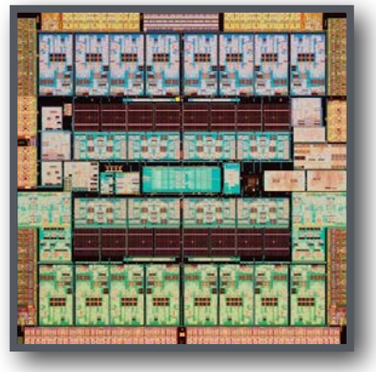
controls the access to hardware resources (cpu, memory, input/output devices, etc.) and acts as an interface with application software

# operating system

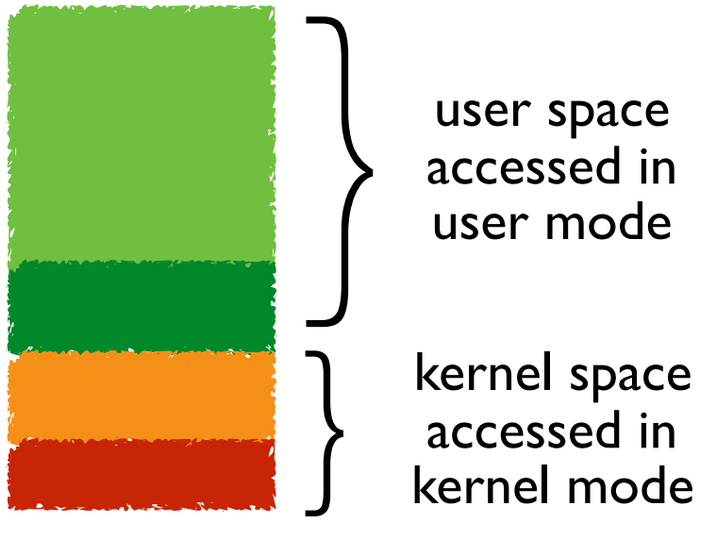



## processor modes

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



## memory protection



# operating system

## resources managed by operating systems

- **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<br>(physical resources) | abstraction<br>(virtual resources) |
|---|---|---|
| CPU | ***n parallel cores*** | ***m concurrent threads***, *with* ***m*** $\gg$ ***n*** |
| memory | ***subset of $2^k$ addressable memory***<br>*on a* ***k*** *bits machine, e.g., for* ***k = 64***,<br>*this is typically* ***8 to 32 gigabytes*** | ***full $2^k$ addressable memory***<br>*for* ***k = 64***, *this is* ***16 exabytes***<br>***$\cong 16 \times 10^6$ 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*** |

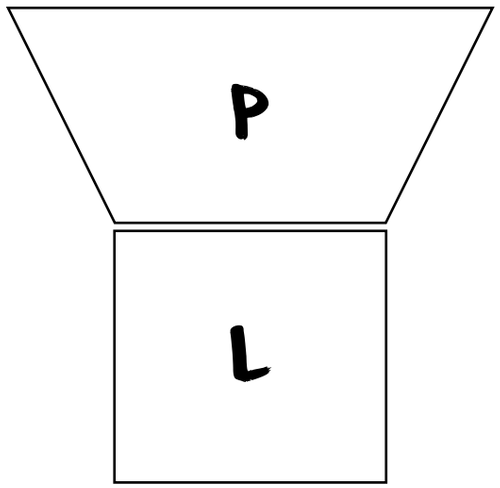
# executions and interpreters

## concept

program P

written in

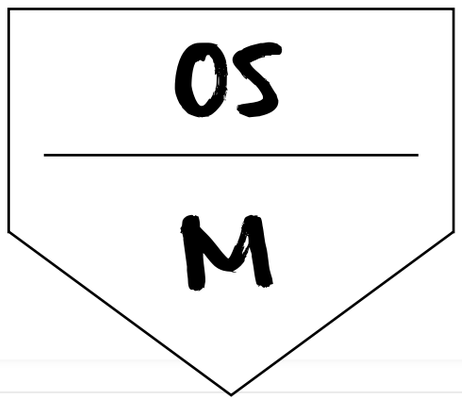
language L



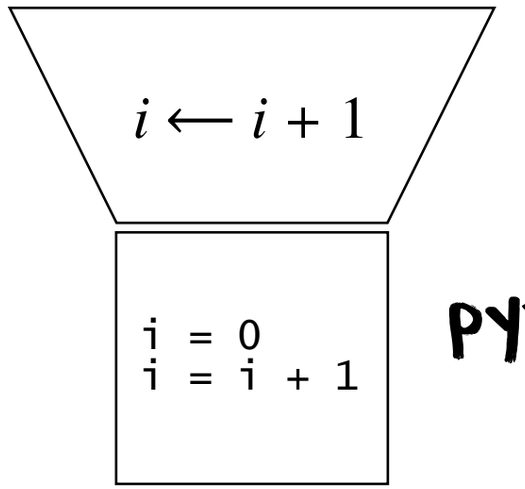

operating system OS

controlling machine

executing language M



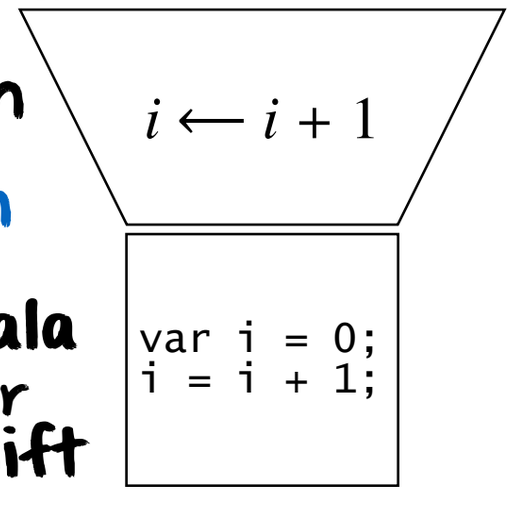

## examples




an addition

written in

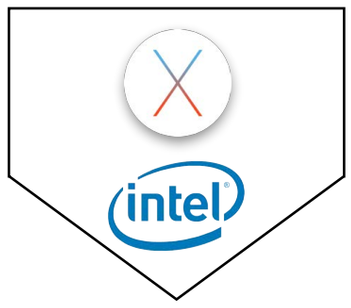
python




scala or swift

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


Samsung S7 running Android on ARM




MacBook Pro running OS X on Intel

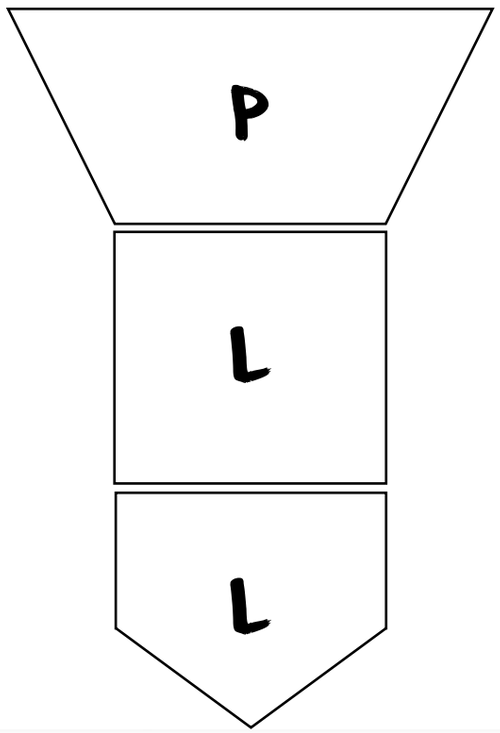

Oracle Server running Solaris on SPARC

machine language M ⇔ instruction set ⇔ byte code

# executions and interpreters

## concept

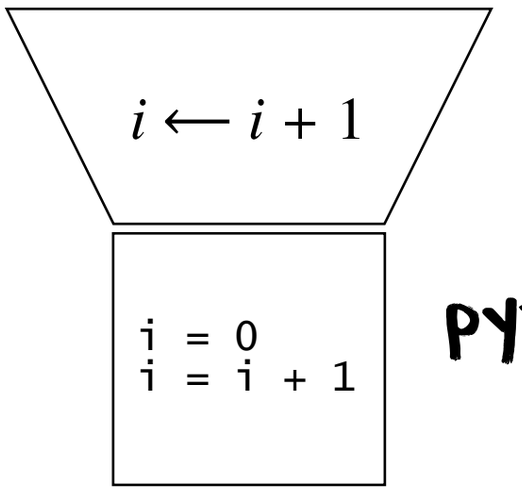
program P
written in
language L
running on
machine L




program language must match machine language

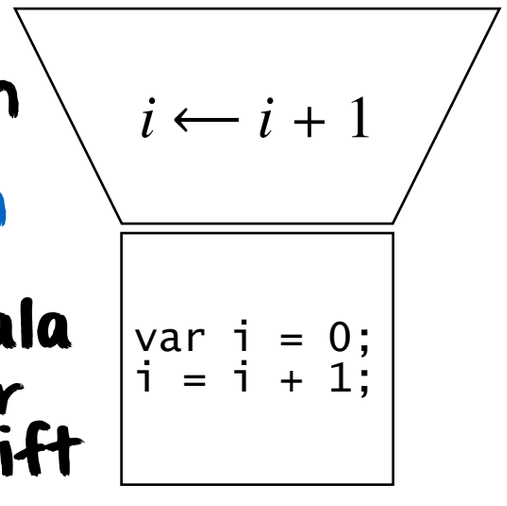
we forget about the operating system for now

## examples




an addition
written in

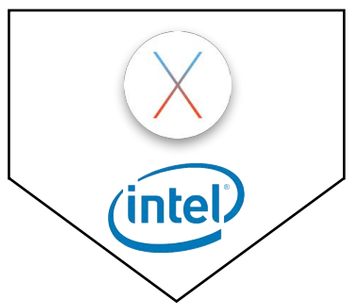
python




scala
or
swift

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


Samsung S7
running Android
on ARM



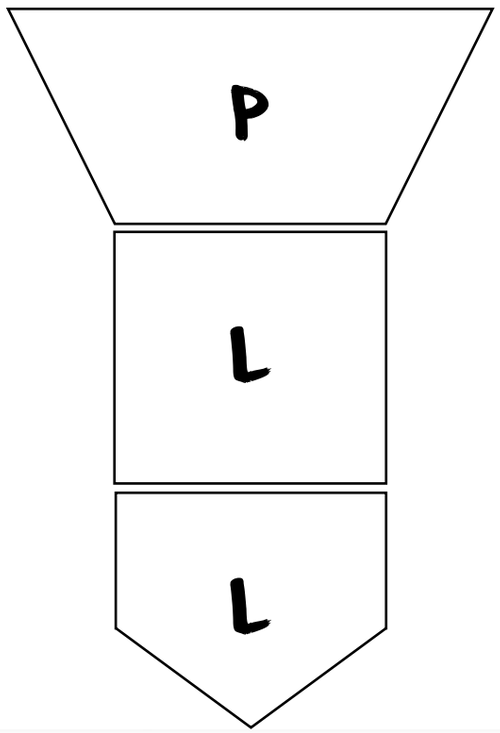

MacBook Pro
running OS X
on Intel


Oracle Server
running Solaris
on SPARC

# executions and interpreters

## concept

program P
written in
language L
running on
machine L



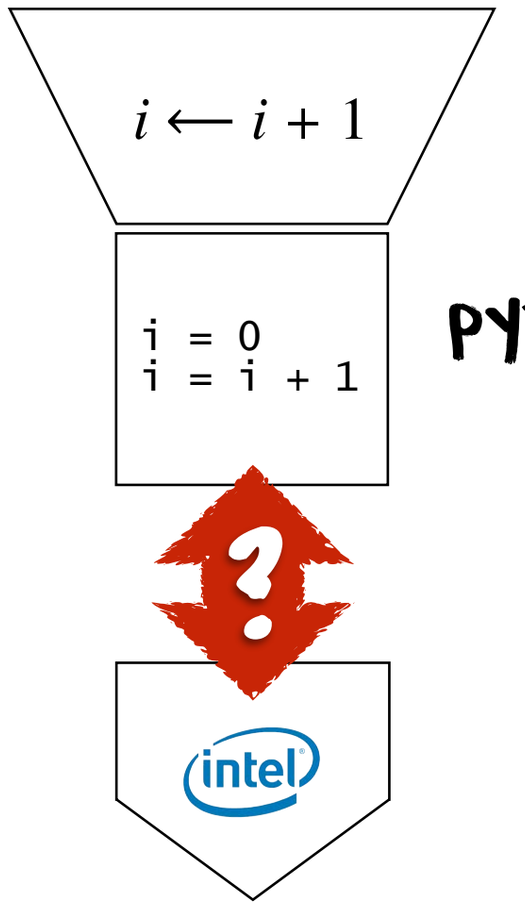

program language must match machine language

we forget about the operating system for now

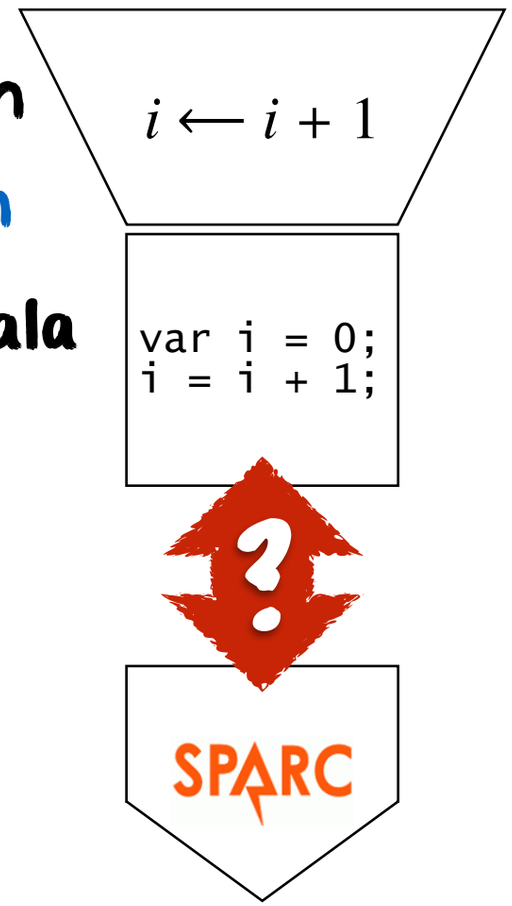
## examples

an addition
written in

python




scala

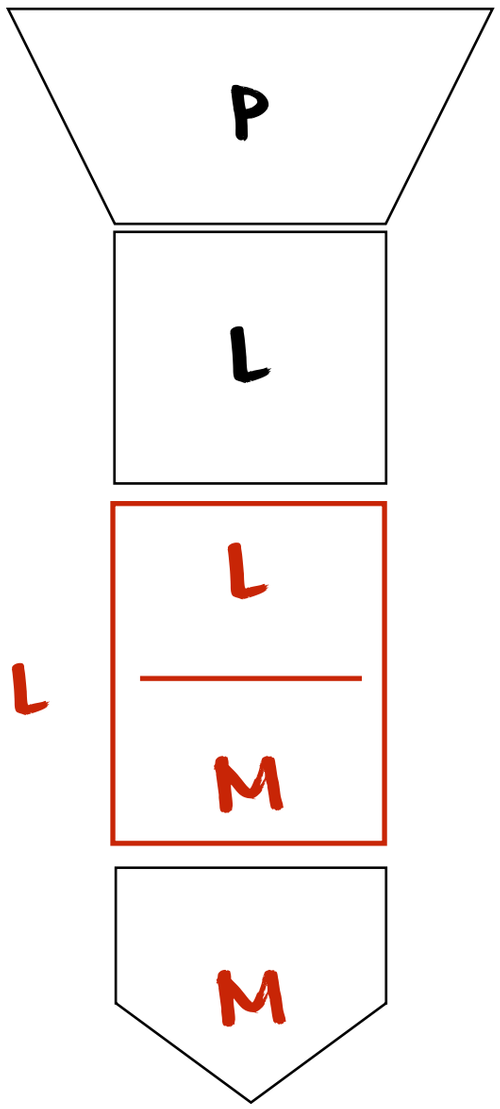



problem!

# executions and interpreters

## concept

program P written in language L




running on interpreter L

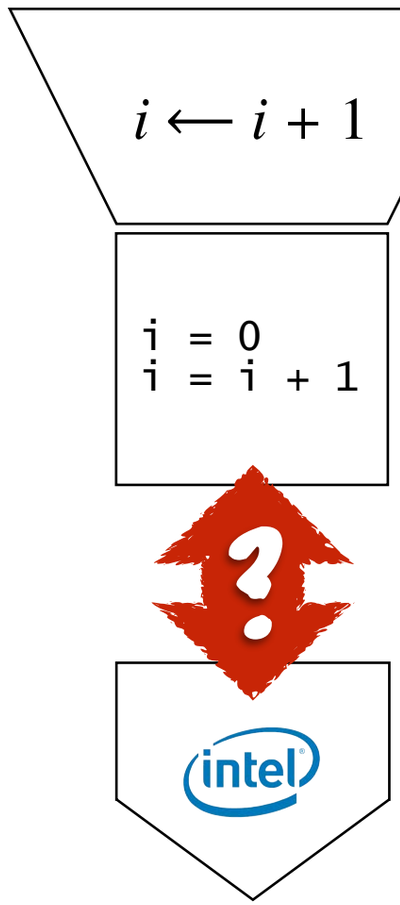
running on machine M

an interpreter dynamically translates language L into language M

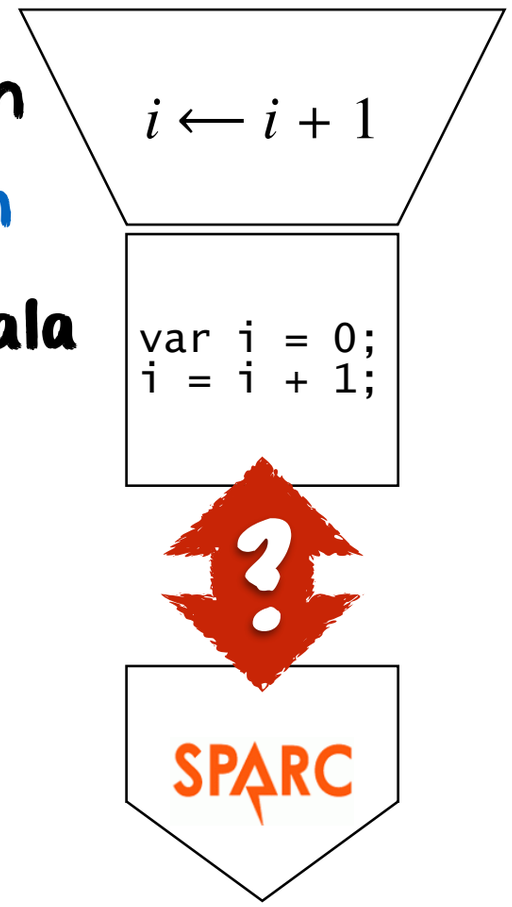
## examples

an addition written in

python




scala




# solution!

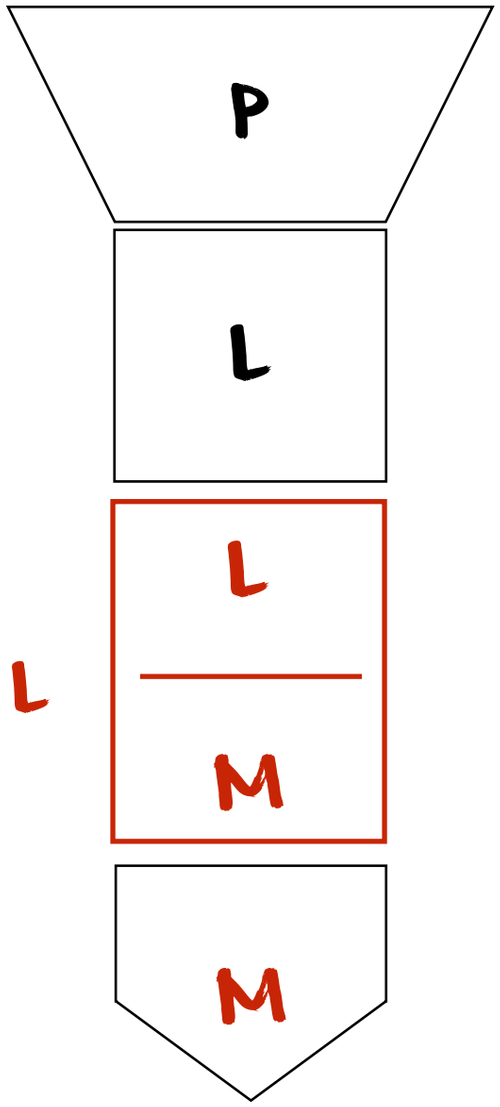
# executions and interpreters

## concept

program P

written in

language L




running on

interpreter L

running on

machine M

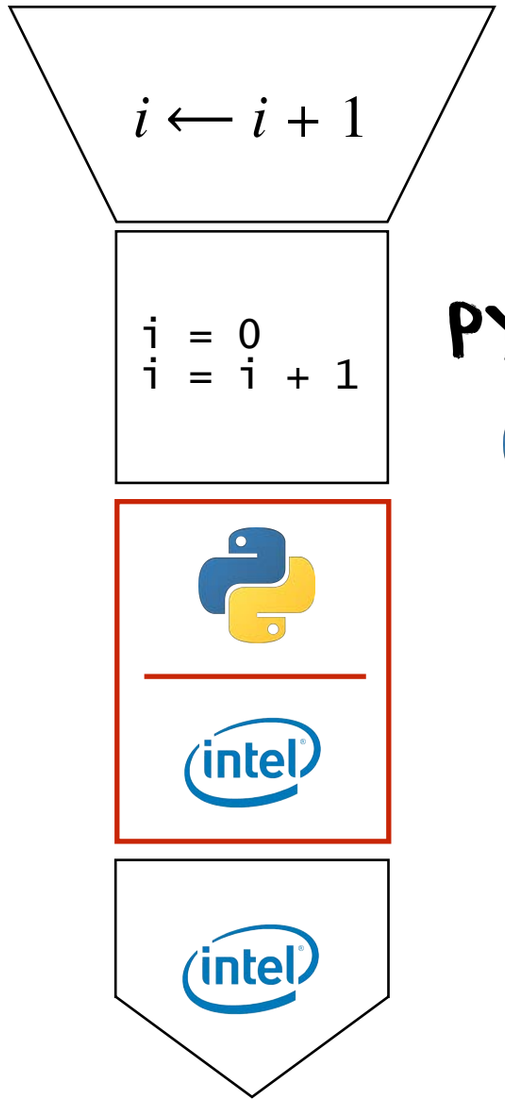
an interpreter dynamically translates language L into language M

## examples

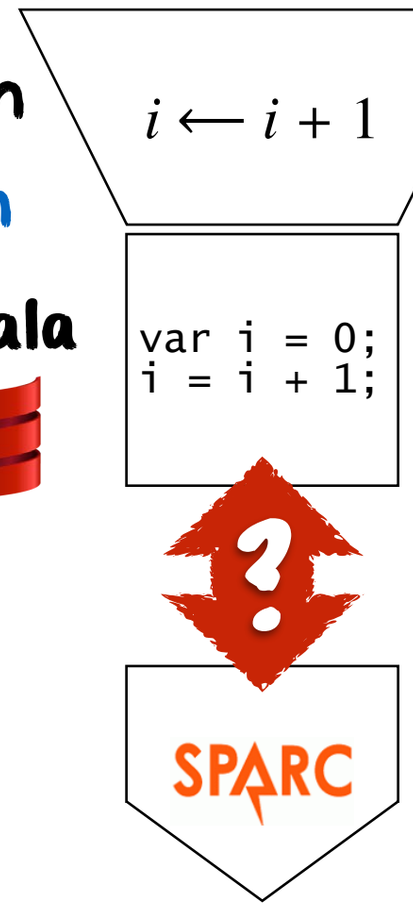
an addition

written in

python



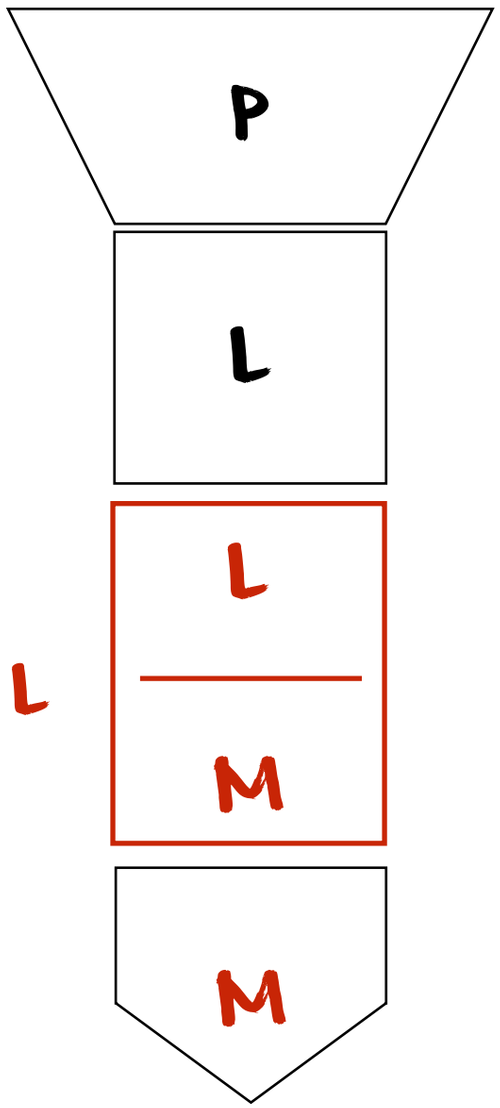

scala



# executions and interpreters

## concept

program P written in language L



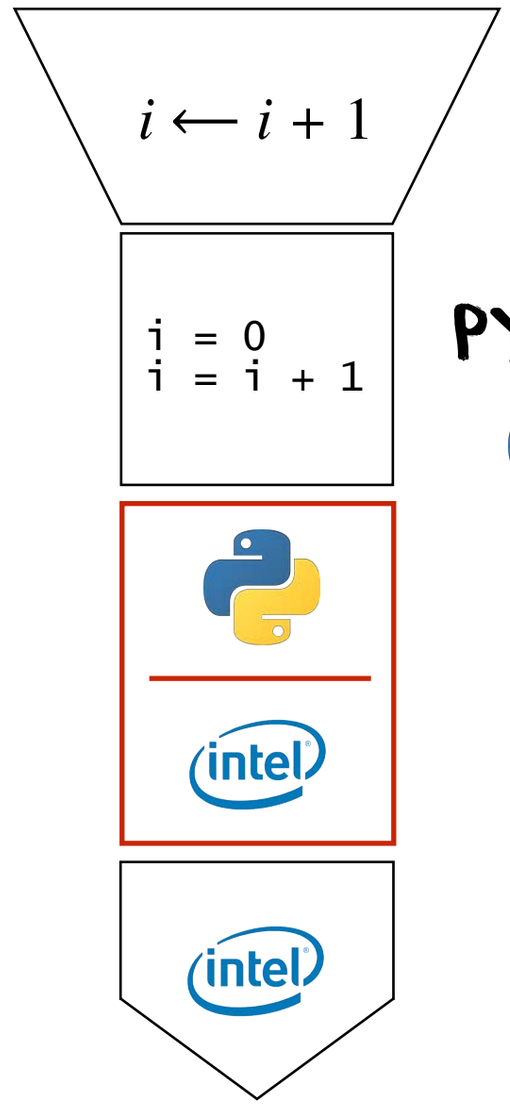

running on interpreter L

running on machine M

an interpreter dynamically translates language L into language M

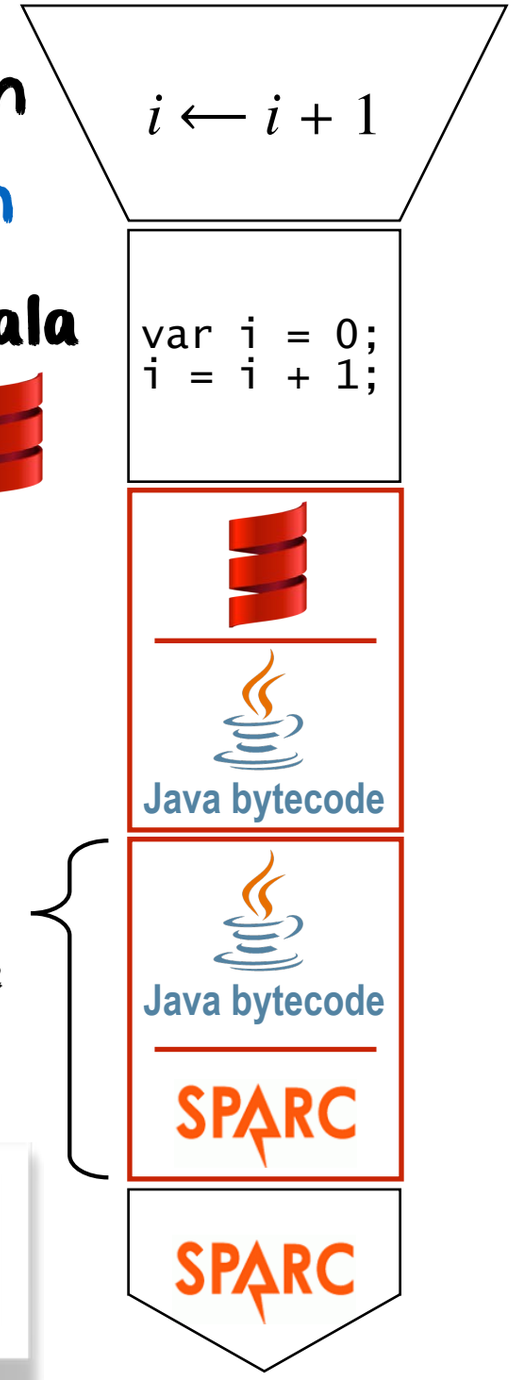
## examples

an addition written in




python

scala




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
```


1001110110001001010110011010011100111001101010...

# what's a compiler

## concept

compiler translating

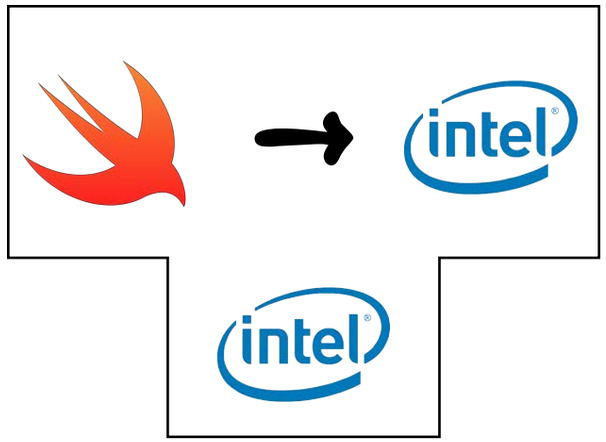
source language S → L target language

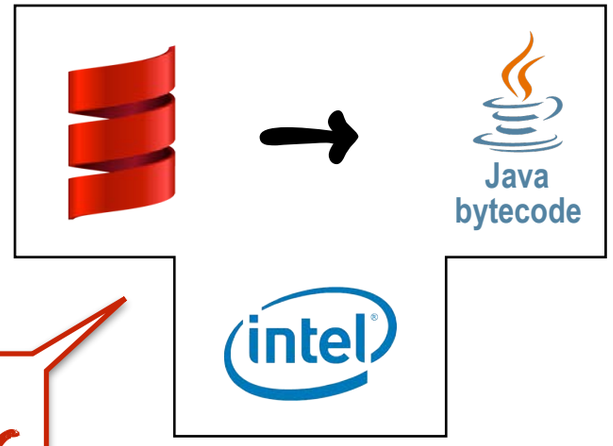
to

M

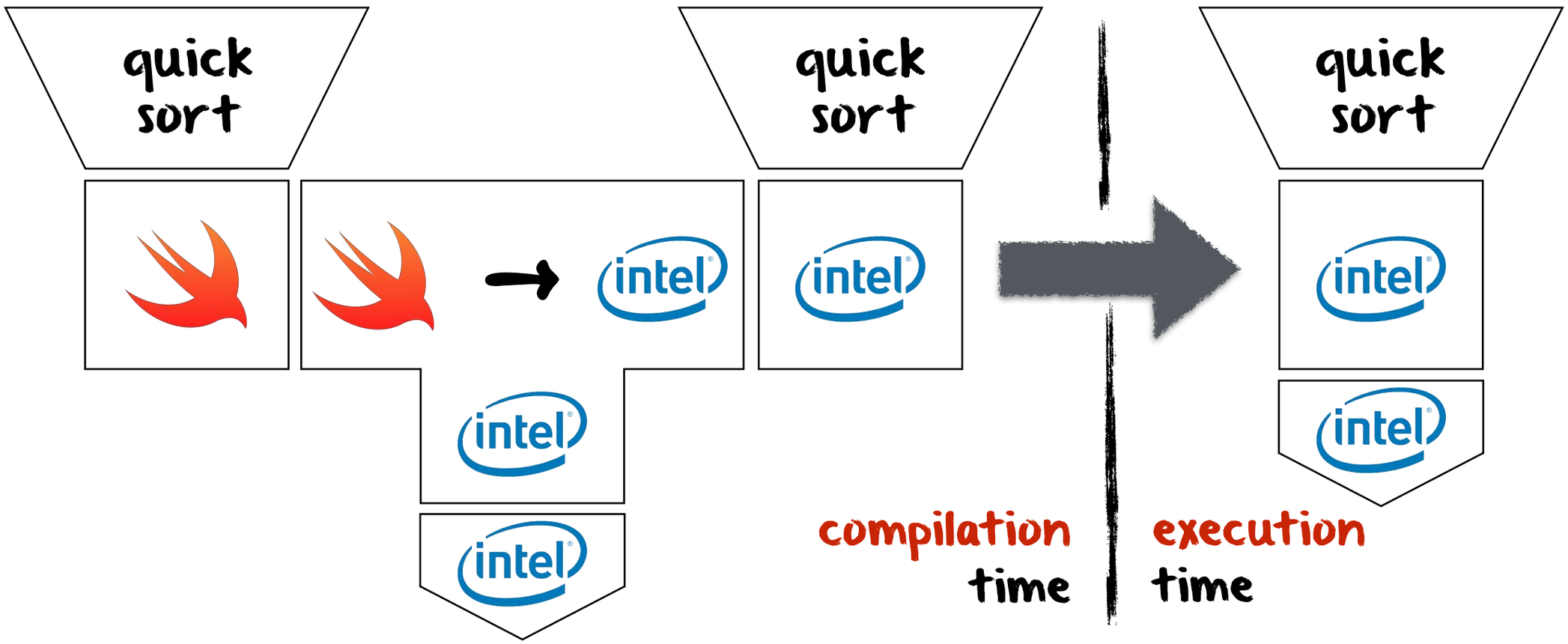
implemented in M

## examples




this is a cross-compiler



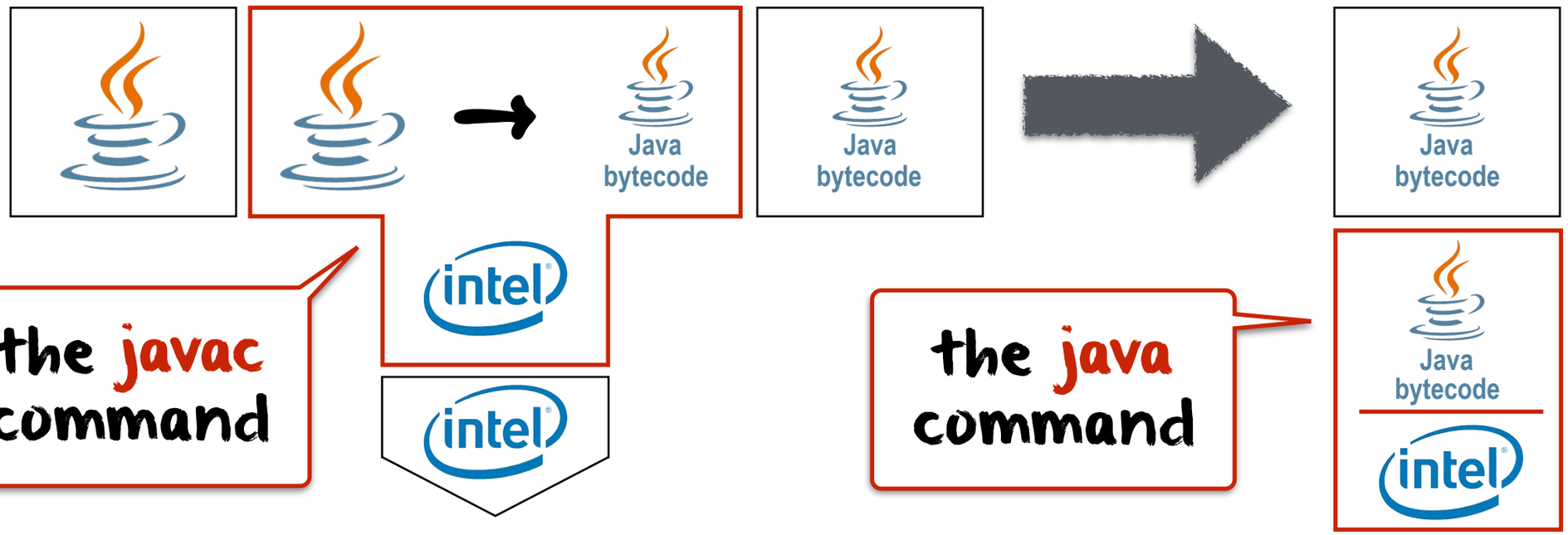
# what's a compiler

the example of java

quick sort

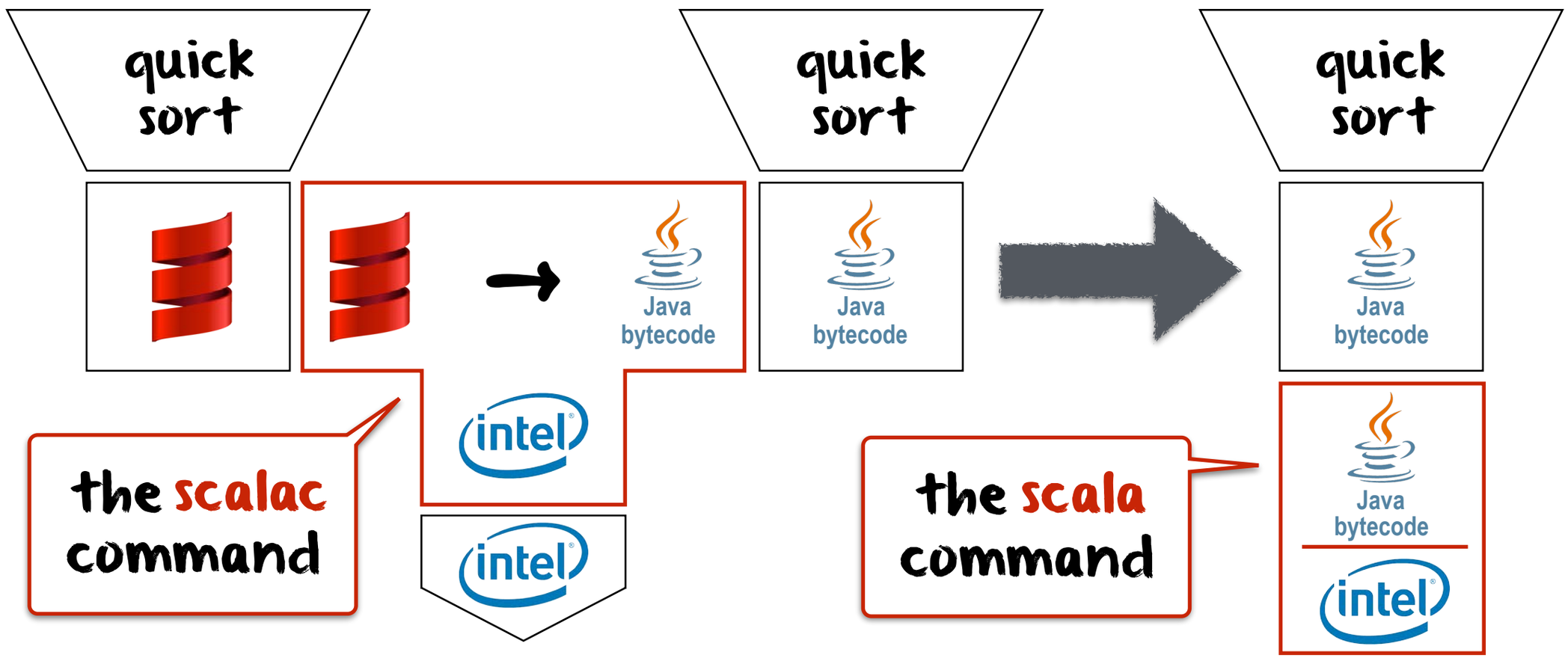
quick sort

quick sort



# what's a compiler

the example of java




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 {
  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(…)?