# E2011: Theoretical fundamentals of computer science
# Introduction to programming languages

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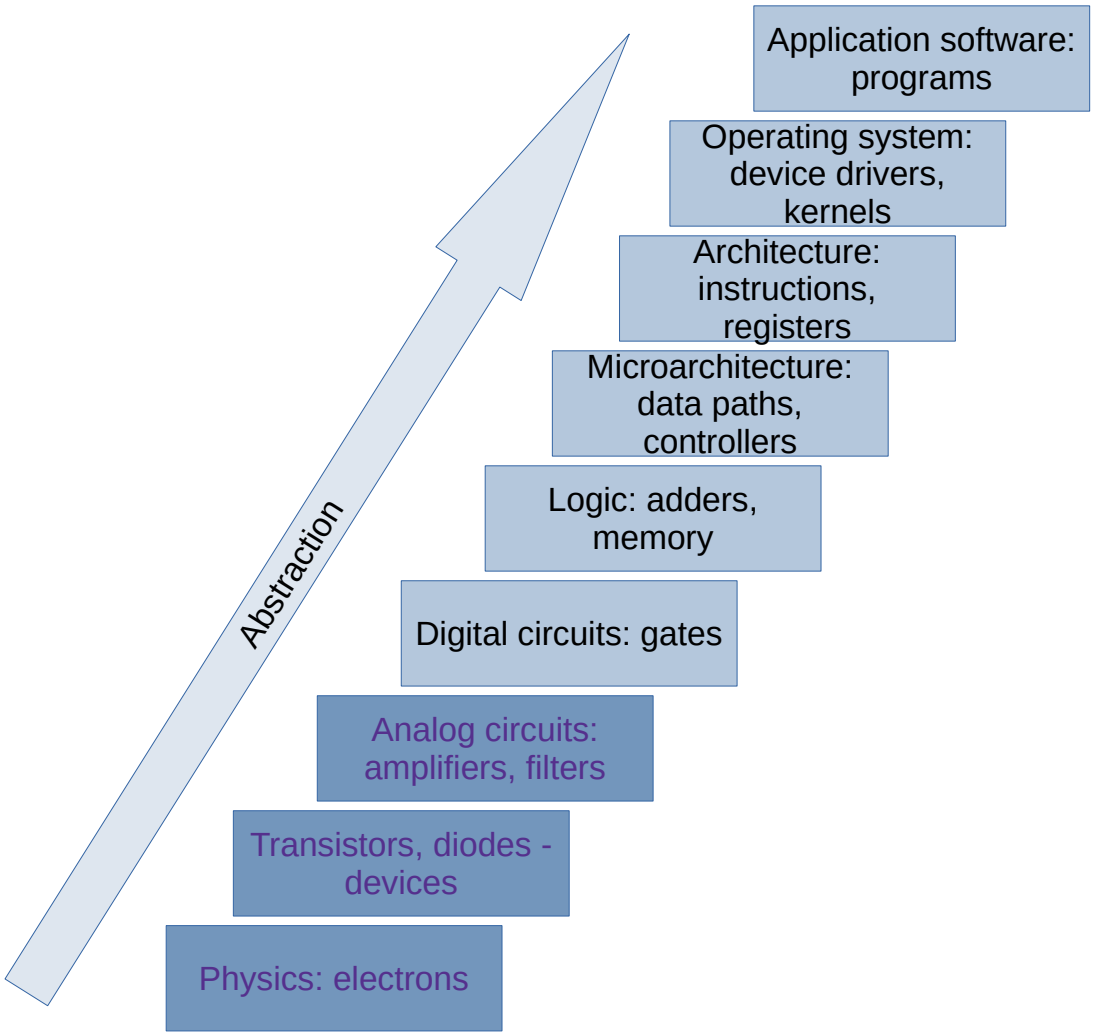
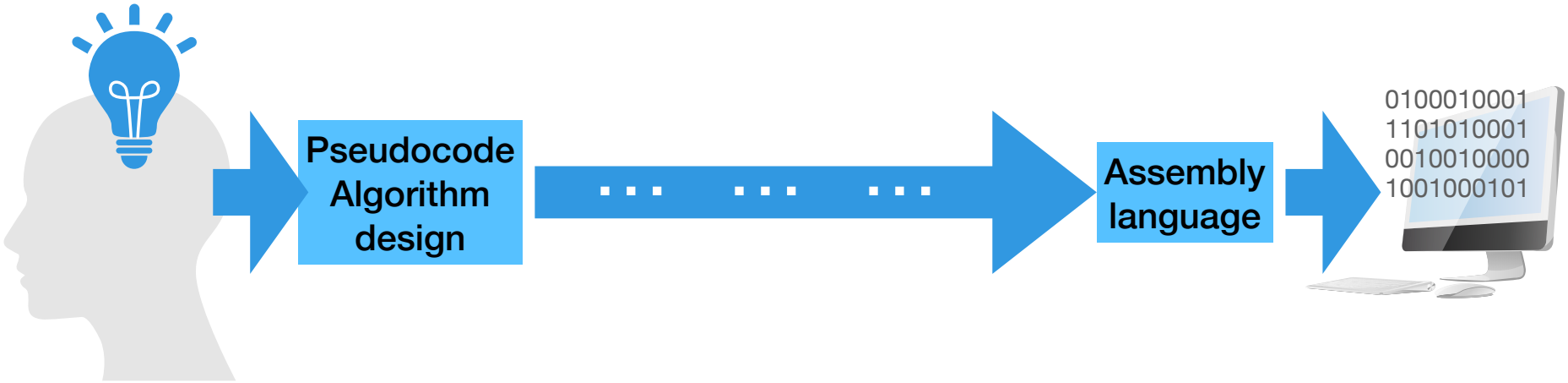
# Outline


Application software: programs
Operating system: device drivers, kernels
Architecture: instructions, registers
Microarchitecture: data paths, controllers
Logic: adders, memory
Digital circuits: gates
Analog circuits: amplifiers, filters
Transistors, diodes - devices
Physics: electrons
Abstraction


Pseudocode
Algorithm
design
Assembly
language
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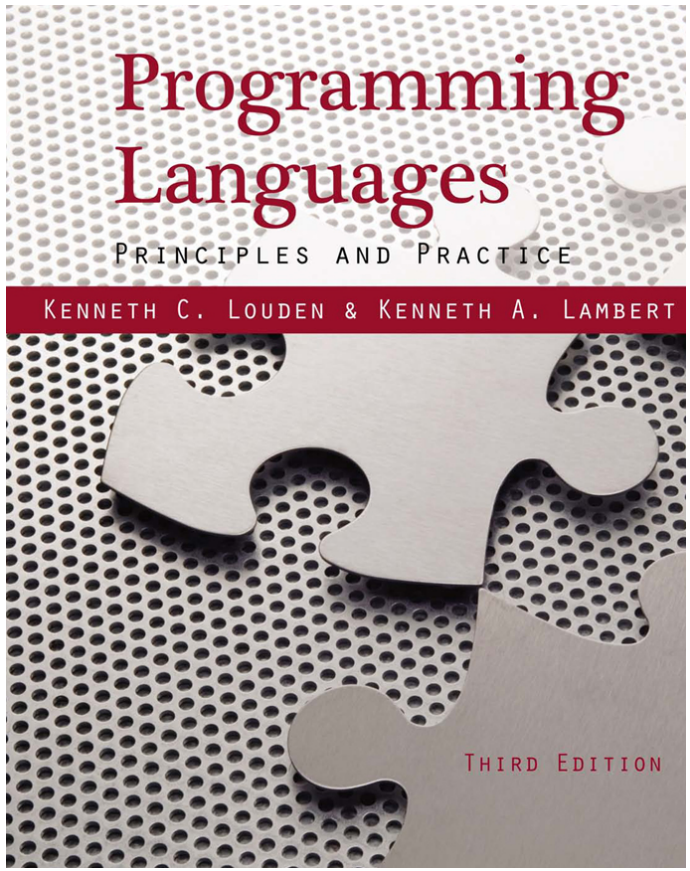
# Programming languages

"How we communicate influences how we think and vice versa."

"Similarly, how we program computers influences how we think about computation, and vice versa."



# Programming languages

- it is a formal computation specification means
- it has a strict **syntax** specified by a **grammar**
- clear **semantics** for each syntactic construct
- various practical implementations:
  - real vs virtual machine
  - translation vs. compilation vs. interpretation

# Levels of abstraction

- algebraic notation and floating point numebers: FORTRAN
- structured abstractions and machine independence Algol, Pascal
- architecture independence ($\lambda-$calculus, Lisp)

# Levels of data abstraction

- basic: variables, data types, declarations
- structured abstractions: data structures, arrays
- unit abstractions: abstract data types (ADTs), classes, packages, namespaces
- information hiding, modularity, reusability, interoperability

# Main programming paradigms

- *imperative*/procedural (e.g., C, C++): variables, assignment, other operators
- *functional* (e.g., Lisp, Scheme, ML, Haskell): abstract notion of a function, based on $\lambda-$calculus
- *logic* (e.g., Prolog): symbolic logic (e.g., predicate calculus)
- *object–oriented* (e.g., Java, Python, C++): encapsulation of data and control together
- *generic* (e.g., C++ and especially its standard library - STL): type abstraction and enforcement mechanisms
- several paradigms may be implemented in the same language
- (multi-paradigm languages)

# Imperative languages

- *variables and assignments*
- *sequential execution*
- *conditionals* (if-then-else) and *loops* (for-do, while-do, and do-while) are the building blocks
- *subroutines/functions/procedures* for procedural abstraction
- efficiency and low-level control

# Example - pseudocode

**Algorithm 1** Sum of odd elements of a vector

**Require:** $x_i \in \mathbb{N}, i = 1, \ldots, n$
**Ensure:** $S$, sum of odd elements
  $S \leftarrow 0$
  **for all** i=1,. . . , n **do**
    **if** $x_i \bmod 2 \neq 0$ **then**
      $S \leftarrow S + x_i$
    **end if**
  **end for**

**Algorithm 2** Sum of odd elements of a vector

**Require:** $x_i \in \mathbb{N}, i = 1, \ldots, n$
**Ensure:** $S$, sum of odd elements
  **function** $\mathrm{SOE}(V)$
    **if** $|V| = 0$ **then**
      **return** 0
    **end if**
    $x \leftarrow \mathrm{head}(V)$
    **if** $x \bmod 2 \neq 0$ **then**
      **return** $x + \mathrm{SOE}(\mathrm{tail}(V))$
    **else**
      **return** $\mathrm{SOE}(\mathrm{tail}(V))$
    **end if**
  **end function**
  $S \leftarrow \mathrm{SOE}([x_1, \ldots, x_n])$

# Imperative languages - sum of odd elements in C

```
#include <stdio.h>

int main() {
  int vector[] = {1, 2, 3, 4, 5, 6, 7, 8, 9}; // some data
  int size = sizeof(vector) / sizeof(vector[0]);
  int sum = 0;

  for (int i = 0; i < size; i++) {
    if (vector[i] & 1) { // use bit-wise AND
      sum += vector[i]; // Add odd element to the sum
    }
}

printf("Sum of odd elements in the vector: %d\n", sum);

return 0;
}
```

# Imperative languages - example in Fortran 95

```
program sum_odd_elements_vectorized
implicit none
integer, parameter :: n = 9
integer :: vector(n) = [1, 2, 3, 4, 5, 6, 7, 8, 9]
integer :: sum

sum = sum(vector(mod(vector, 2) /= 0))

print *, 'Sum of odd elements in the vector:', sum
end program sum_odd_elements_vectorized
```

# Functional programming

## $\lambda-$**calculus**

- Alonzo Church, 1930s
- formal basis of all functional languages
- *infix notation*
- syntax:

$$\begin{aligned} \mathit{expression} \rightarrow\ & \mathit{constant} \\ |\ & \mathit{variable} \\ |\ & (\mathit{expression}\,\mathit{expression}) \\ |\ & (\lambda \mathit{variable}.\mathit{expression}) \end{aligned}$$

- example

$$(\lambda x.+1\ x)\ 2 \Rightarrow (+1\ 2) \Rightarrow 3$$

# Examples

Examples of FL: Haskell, JavaScript, Scala, Erlang, Lisp, ML, Clojure, OCaml, Lisp, etc. etc.

## Lisp

```
(defun sum-odd-elements (lst)
  (if (null lst)
    0
    (if (oddp (car lst))
      (+ (car lst) (sum-odd-elements (cdr lst)))
      (sum-odd-elements (cdr lst)))))

(let ((vector '(1 2 3 4 5 6 7 8 9)))
  (format t "Result: ~a" (sum-odd-elements vector)))
```

## OCaml

```
let rec sum_odd_elements lst =
  match lst with
    | [] -> 0
    | hd :: tl ->
      if hd mod 2 <> 0 then
        hd + sum_odd_elements tl
      else
        sum_odd_elements tl

let () =
  let vector = [1; 2; 3; 4; 5; 6; 7; 8; 9] in
  let result = sum_odd_elements vector in
  Printf.printf "Sum of odd elements in the list: %d\n" result
```

# Logic programming

- based on *logical statements*
- uses *first order predicate calculus*; ingredients
  - variables: e.g. $x, y, z$
  - constants: e.g. $1, 2, a, b$
  - predicates: e.g. $P(x), Q(y)$, properties or relationships that can be true or false for objects or values
  - quantifiers: *universal quantifier* $\forall$, e.g.$\forall\ x\ P(x)$, and *existential quantifier* $\exists$, e.g. $\exists\ x\ P(x)$
  - connectives: AND ($\wedge$), OR ($\vee$), NOT ($\neg$), and IMPLIES ($\rightarrow$)
- example: $\forall\ x\ (P(x) \rightarrow Q(x))$ means "for all values of x, if P(x) is true, then Q(x) is also true"

# Prolog

## Example 1: family relations

```
male(harry).
female(liz).

parent(phil, chas).
parent(liz, chas).
parent(chas,harry).
parent(chas,wills).

grandmother(GM, C):-
        mother(GM, P),
        parent(P, C).

mother(M,C):-
        female(M),
        parent(M, C).

% Run: grandmother(liz, Who).
% Result: Who=harry and Who=wills
```

## Example 2 (recursion): sum of elements from a list

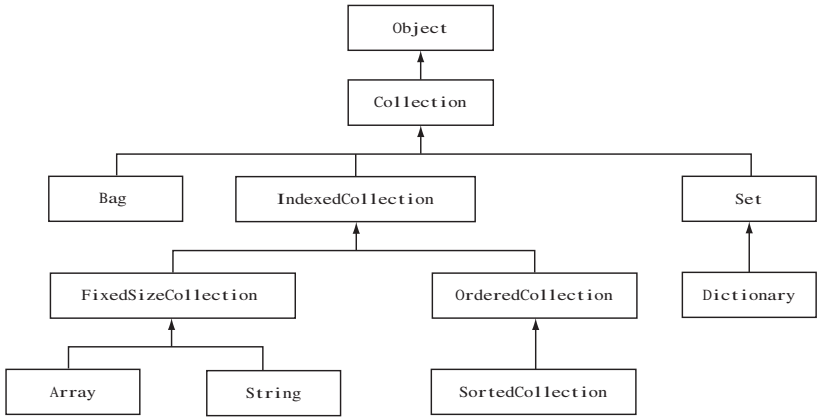
```
sumlist([],0).
ssumlist([H|T],N) :-
        sumlist(T,N1),
        N is N1+H.
```

## Example 3: sum of odd elements

```
sum_odd_elements([], 0).

sum_odd_elements([Head|Tail], Sum) :-
  0 is Head mod 2, % If Head is even,
  sum_odd_elements(Tail, Sum). % skip Head

sum_odd_elements([Head|Tail], Sum) :-
  1 is Head mod 2, % If Head is odd,
  sum_odd_elements(Tail, TailSum), % sum of odd elem. in Tail,
  Sum is Head + TailSum. % and add Head to the sum.

% Example usage:
% sum_odd_elements([1, 2, 3, 4, 5, 6, 7, 8, 9], Result).
% Result will contain the sum of odd elements: 25
```

# Object-Oriented Programming

- satistifes three important needs:
  - reusability
  - minimal changes for modifying behaviour
  - independence of components
- extension of data and/or operations
- redefinition of operations
- abstraction
- polymorphism



## Java

```
public class SumOddElements {
  public static void main(String[] args) {
    int[] vector = {1, 2, 3, 4, 5, 6, 7, 8, 9};
    int sum = 0;

    for (int element : vector) {
      if (element % 2 != 0) { // Check if the element is odd
        sum += element; // Add odd element to the sum
      }
    }

    System.out.println("Result:-" + sum);
  }
}
```

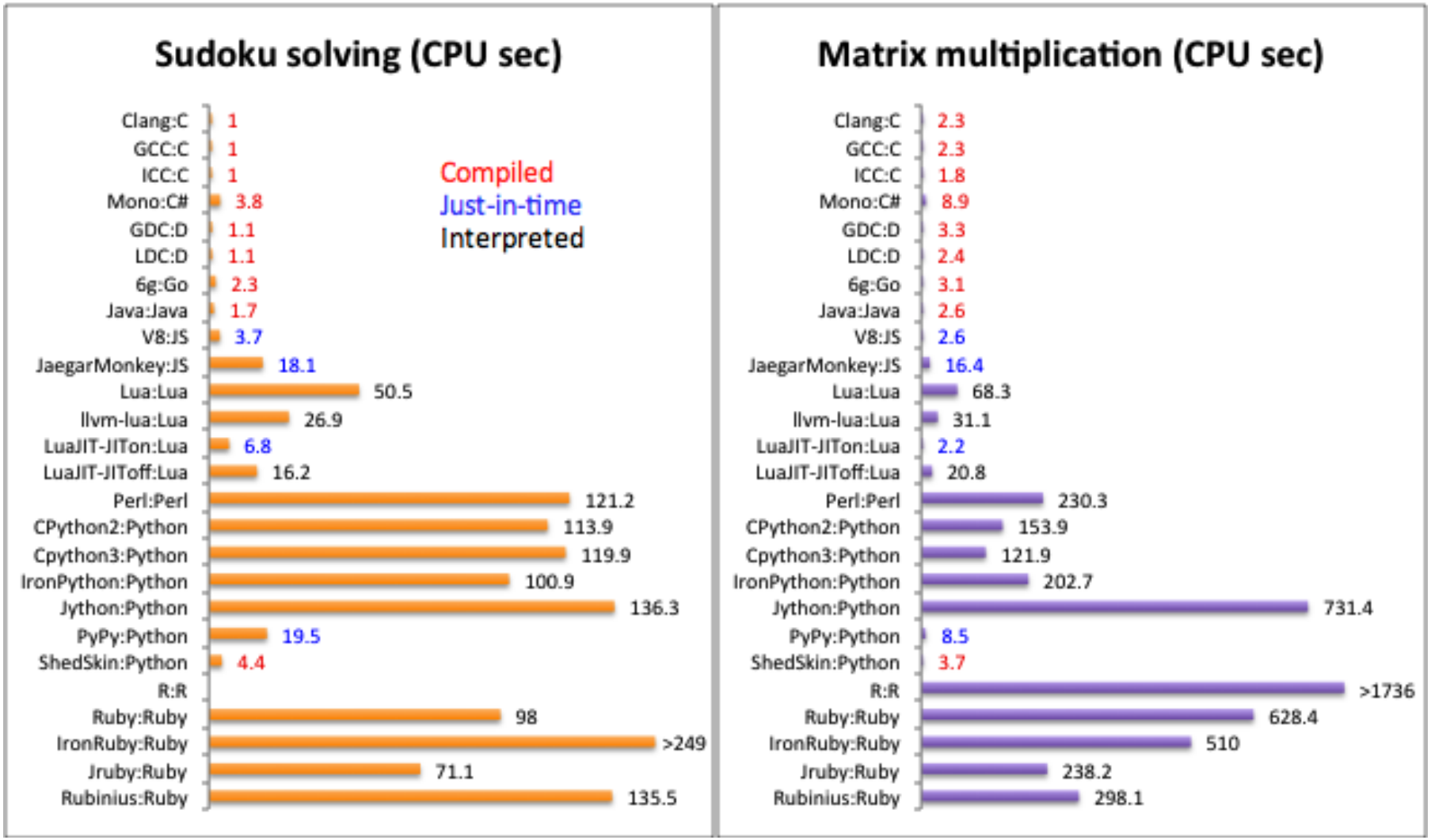
**Python** - while OOP, does not impose it

```
vector = [1, 2, 3, 4, 5, 6, 7, 8, 9]
sum = 0

for element in vector:
    if element % 2 != 0:
        sum += element

print("Sum of odd elements in the list:", sum)
```

# Programs: from code to execution

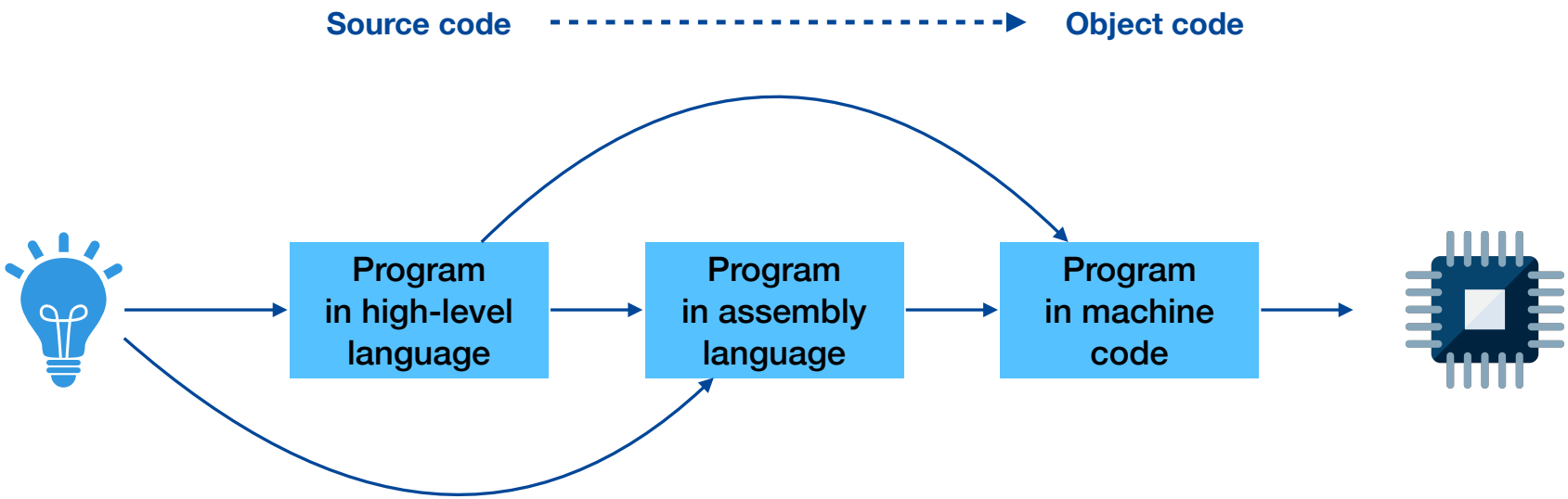
- the *source code* is not directly runnable on the CPU
- means to run a program
  - *compilation* - ahead-of-time compilation for *compiled languages* (e.g. C/C++/Fortran...)
  - *interpretation* - a special software interprets and executes the instructions in a program - for *interpreted languages* (e.g. Lisp, Prolog, Python)
  - *just-in-time compilation* for programs running on virtual machines (e.g. Java, Python (CPython))
- compilation allows code optimization
- sometimes several techniques are used for a single language: e.g. Java is compiled to bytecode, runs on VM and has a JIT

# AOT vs JIT vs interpretation




from https://attractivechaos.github.io/plb/

# AOT compilation

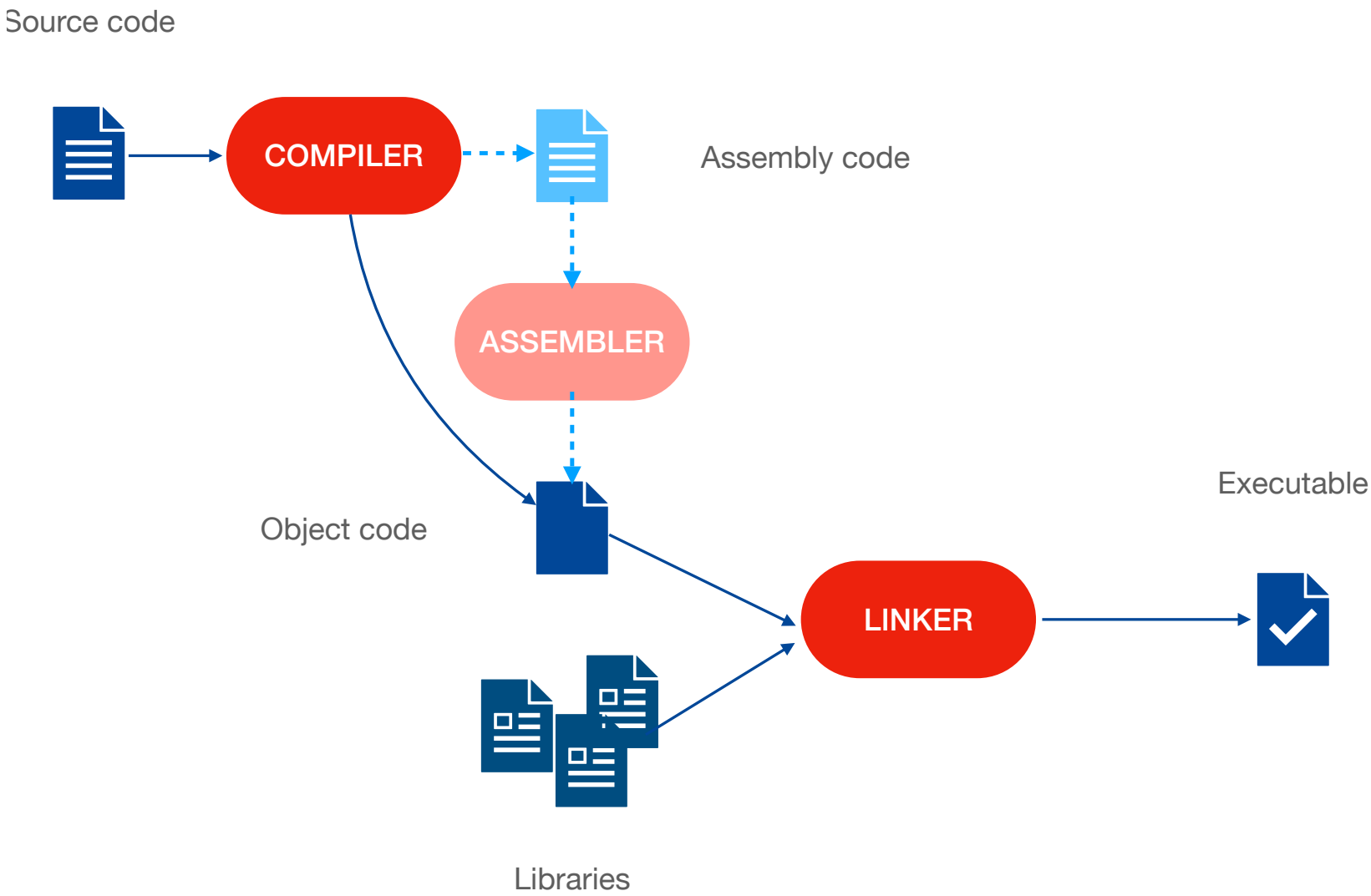



```
# let rec sort = function
    | [] -> []
    | x :: l -> insert x (sort l)
  and insert elem = function
    | [] -> [elem]
    | x :: l -> if elem < x then elem :: x :: l
                else x :: insert elem l;;
```

```
mov ax,'00'
mov di,counter
mov cx,digits+cntDigits/2
cld
rep   stosw
inc   ax
mov [num1 + digits - 1],al
mov [num2 + digits - 1],al
mov [counter + cntDigits - 1],al
```

```
0100010001
1101010001
0010010000
1001000101
```

- Advantages:
  - efficiency
  - privacy
  - offline execution: no need for the original source code
- Disadvantages:
  - low portability
  - build complexity and time


Source code
COMPILER
Assembly code
ASSEMBLER
Object code
Executable
LINKER
Libraries

# Interpretation

- there is an *interpreter* software that reads and executes the program instruction-by-instruction
- supports "write-once-execute-everywhere" idea
- Advantages:
  - portability
  - dynamic features
  - ease of debugging
- Disadvantages:
  - low performance
  - dependency on interpreter
- examples: Python, R

# Virtual machines and JIT

- VM: an abstract machine (program) that runs the *bytecode* represenation of the program
- the program is compiled to bytecode either by AOT compiler or by a *just-in-time (JIT)* compiler
- JIT may operate at various time points and different granularity to optimize the (byte)code
- Advantages: portability and good performance
- Disadvantages: overhead and dependency on VM
- example: Java Virtual Machine (JVM) contains bothseveral an interpreter for bytcode, a compiler from code to bytecode and from an optimizing JIT
- there are also JITs for other interpreted languages (e.g. Python)

If you're curious about other programming languages, check out `http://helloworldcollection.de`

# Questions?