CS558 Programming Languages

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Lecture 1a

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What programming languages do you know?

What programming languages do you know?

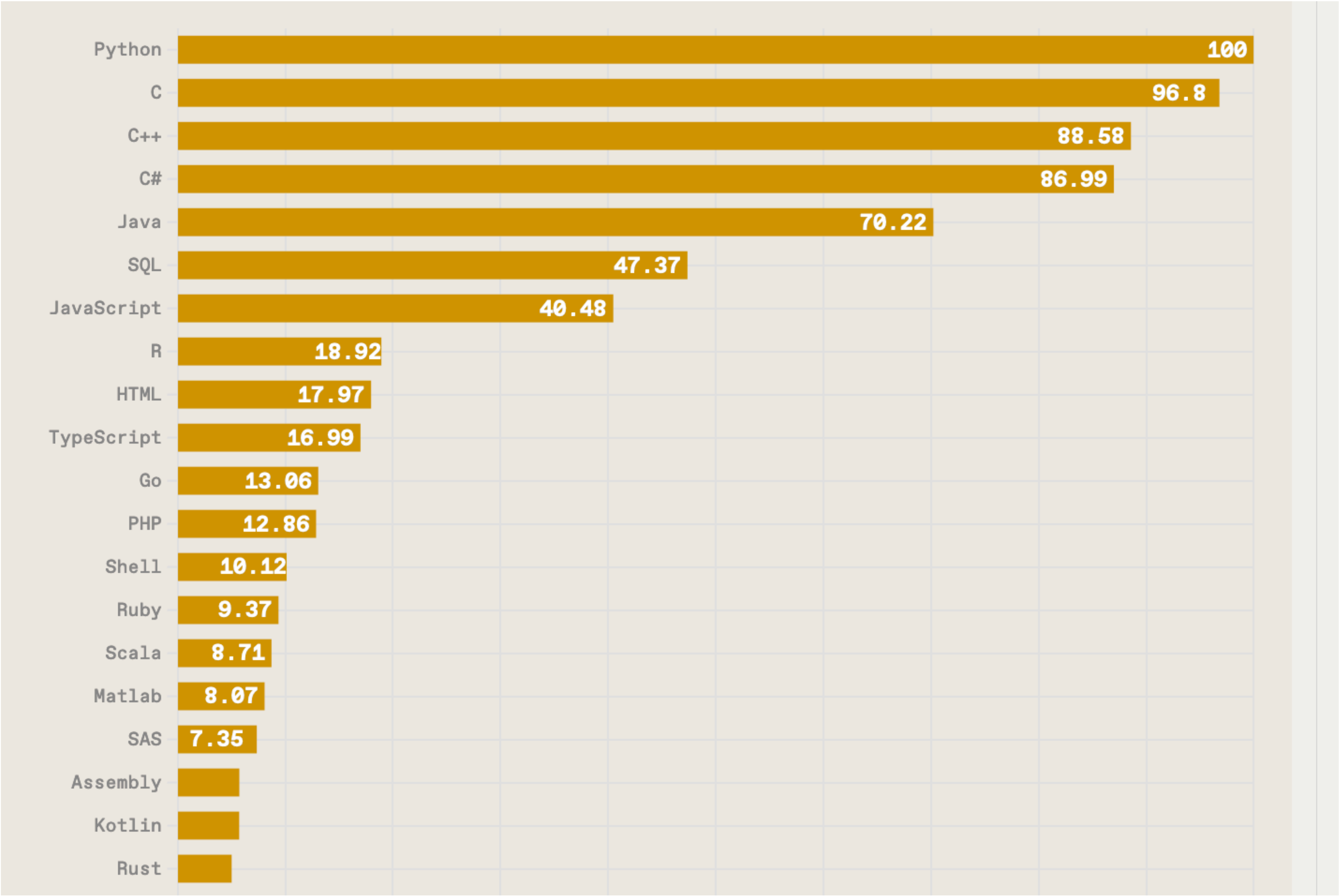
Some historically interesting and/or currently visible languages:

FORTRAN, COBOL, (Visual) BASIC, ALGOL-60, ALGOL-68, PL/I, C, C++, RPG, Pascal, Modula, Lisp, Scheme, ML, Haskell, F#, Ada, Prolog, Curry, Snobol, ICON, Java, C#, JavaScript, Go, Dart, Swift, Rust, perl, tcl, Python, MATLAB, R, . . .

Don’t forget things like:

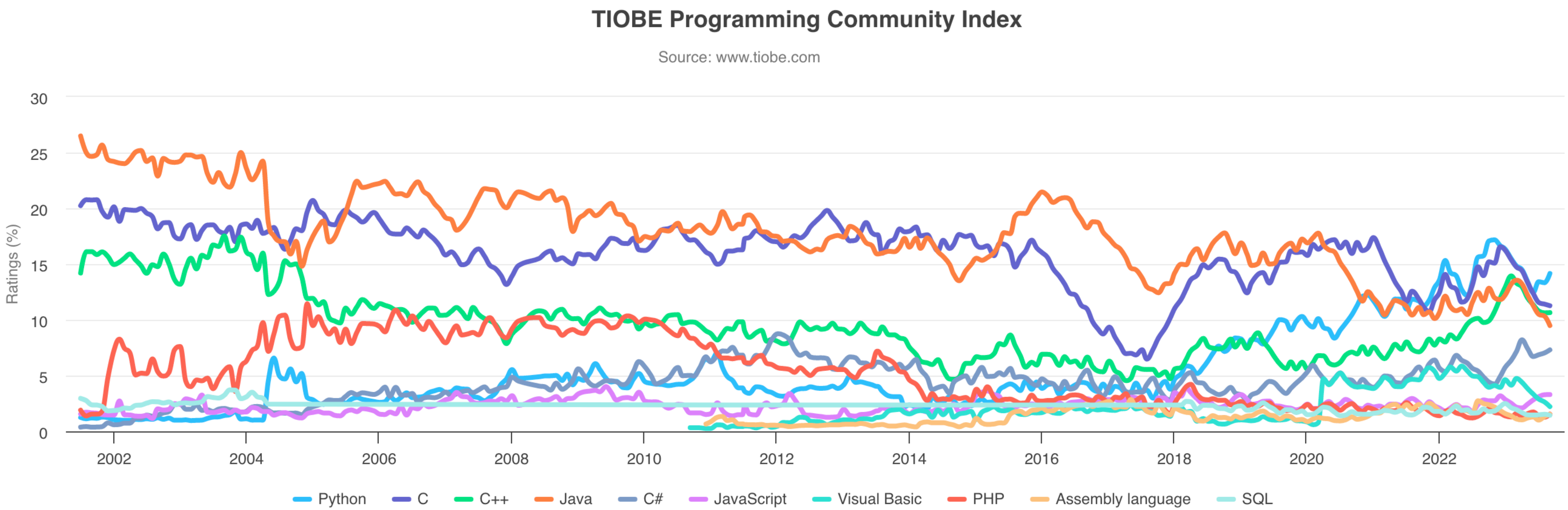
- HTML, PHP, other web page description languages
- SQL, other database query languages
- EXCEL formula language

What languages?



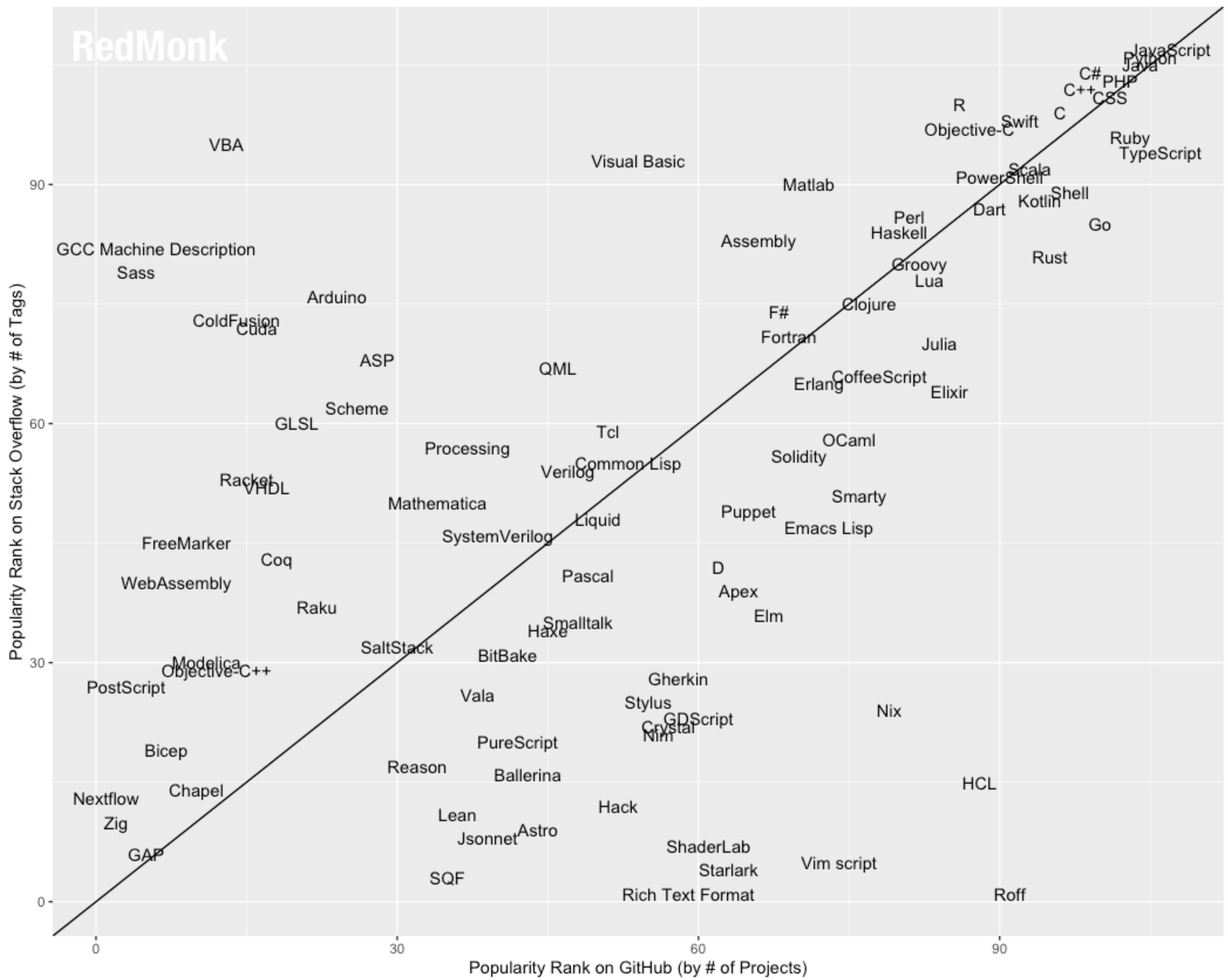
Source: spectrum.ieee.org/top-programming-languages-2022

What languages?



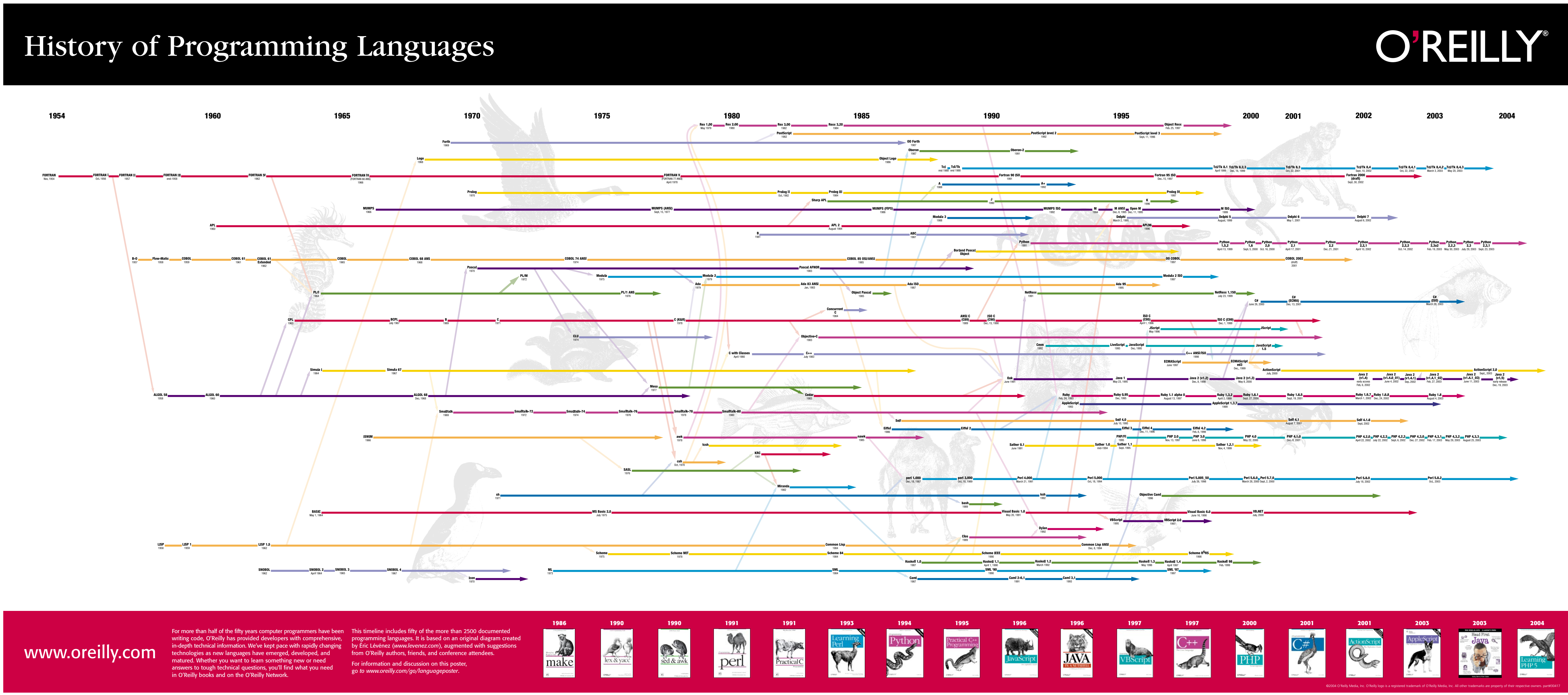
What languages?

RedMonk Q123 Programming Language Rankings



Source:https://redmonk.com/sogrady/2023/05/16/language-rankings-1-23/

What languages?



“Why are coders angry?”

“Programmers...know their position is vulnerable. They get defensive when they hear someone suggest that Python is better than Ruby, because [insert 500-comment message thread here]. Is the next great wave swelling somewhere, and will it wash away Java when it comes? Will Go conquer Python? Do I need to learn JavaScript to remain profitable? Programmers are often angry because they’re often scared. We are, most of us, stumbling around with only a few candles to guide the way. We can’t always see the whole system, so we need to puzzle it out, bit by bit, in the dark.”

- Paul Ford, “What is Code?”, Bloomberg Businessweek, 6/11/15

Learning Objectives

- Know fundamental building blocks and structure of programming languages, and be able to analyze a language into its features.
- Be able to read and manipulate common formalisms for language syntax and semantics.
- Recognize and program in different language styles, including the object-oriented and functional paradigms.
- Understand the role of types in languages and be able to explain how type checking works in general and on specific programs.
- Understand procedural and data abstraction and analyze how they are supported in specific languages.

Course Method

- Conventional survey textbook, with broad coverage of languages
- Organized around key anatomical features of PLs
  - Expressions, control flow, functional abstraction, state, types, objects, modules, …
- Lab exercises mostly involving implementing interpreters for "toy" languages
- Exercises will use Scala, a modern language that blends the object-oriented (OO) and functional (FP) paradigms

Course Non-Goals

- Teaching you how to program
- Teaching you how to program in Scala
  - although you will learn something about this!
- Surveying the details of lots of languages
- Covering all important programming paradigms
  - e.g. we'll skip logic programming and concurrency
- Learning how real compilers & interpreters are implemented

"High-level" Programming Languages

Consider a simple algorithm for testing primality.

In Scala, using imperative programming style:

```
// return true if n has no divisor in the interval [2,n)
def isPrime(n:Int) : Boolean = {
  for (d <- 2 until n)
    if (n % d == 0)
      return false;
  true
}
```

“High-level” Programming Languages

In Scala, using a local recursive function:

```
// return true if n has no divisor in the interval [2,n)
def isPrime(n:Int) : Boolean = {
  // return true if n has no divisor in the interval [d,n)
  def noDivFrom(d:Int) : Boolean =
    (d >= n) || (n % d != 0) && noDivFrom (d+1)
  noDivFrom(2)
}
```

In Intel X86 assembler

```
.globl isprime
isprime:
      pushl %ebp           ; set up procedure entry
      movl %esp,%ebp
      pushl %esi
      pushl %ebx
      movl 8(%ebp),%ebx    ; fetch arg n from stack
      movl $2,%esi         ; set divisor d := 2
      cmpl %ebx,%esi       ; compare n,d
      jge true             ; jump if d >= n
loop: movl %ebx,%eax       ; set n into ....
      cltd                 ; ... dividend register
      idivl %esi           ; divide by d
      testl %edx,%edx      ; remainder 0?
      jne next             ; jump if remainder non-0
      xorl %eax,%eax       ; set ret value := false(0)
      jmp done
next: incl %esi            ; increment d
      cmpl %ebx,%esi       ; compare n,d
      jl loop              ; jump if d < n
true: movl $1,%eax         ; set ret value := true(1)
done: leal -8(%ebp),%esp   ; clean up and exit
      popl %ebx
      popl %esi
      leave
      ret
```

What makes a language “high-level”?

What makes a language “high-level”?

- Complex expressions (arithmetic, logical,...)
- Structured control (loops, conditionals, cases,...)
- Composite types (arrays, records, ...)
- Type declarations and type checking
- Multiple data storage classes (global/local/heap/ GC?)
- Procedures/functions, with private scope (first class?)
- Non-local control (exceptions, threads,...)
- Data abstraction (ADTs, modules, objects...)

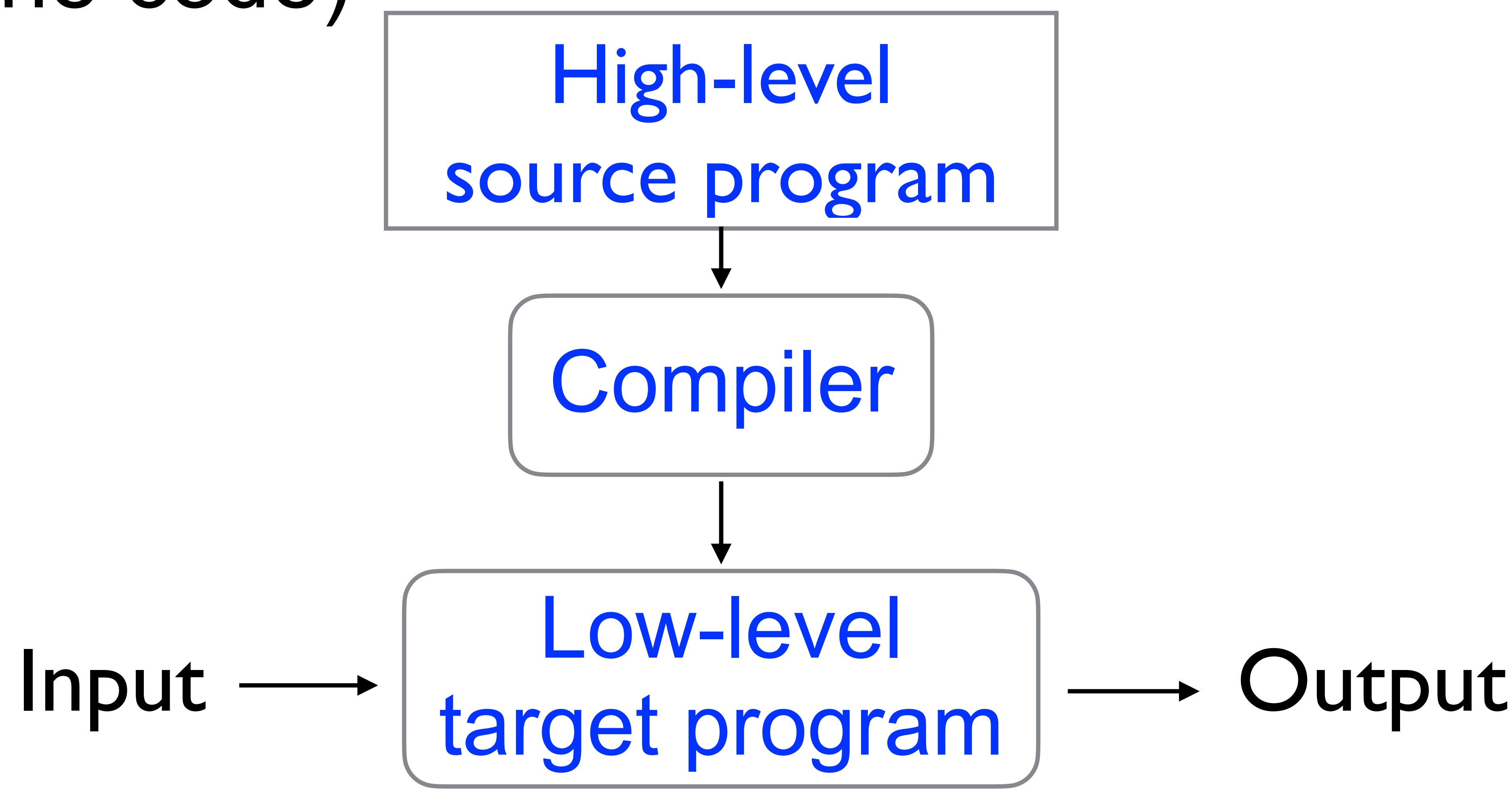
What does hardware give us?

What does hardware give us?

- Low-level machine instructions
- Control flow based on labels and conditional branches
- Explicit locations (e.g. registers) for values and intermediate results of computations
- Flat memory model
- Explicit memory management (e.g., stacks for procedure local data)

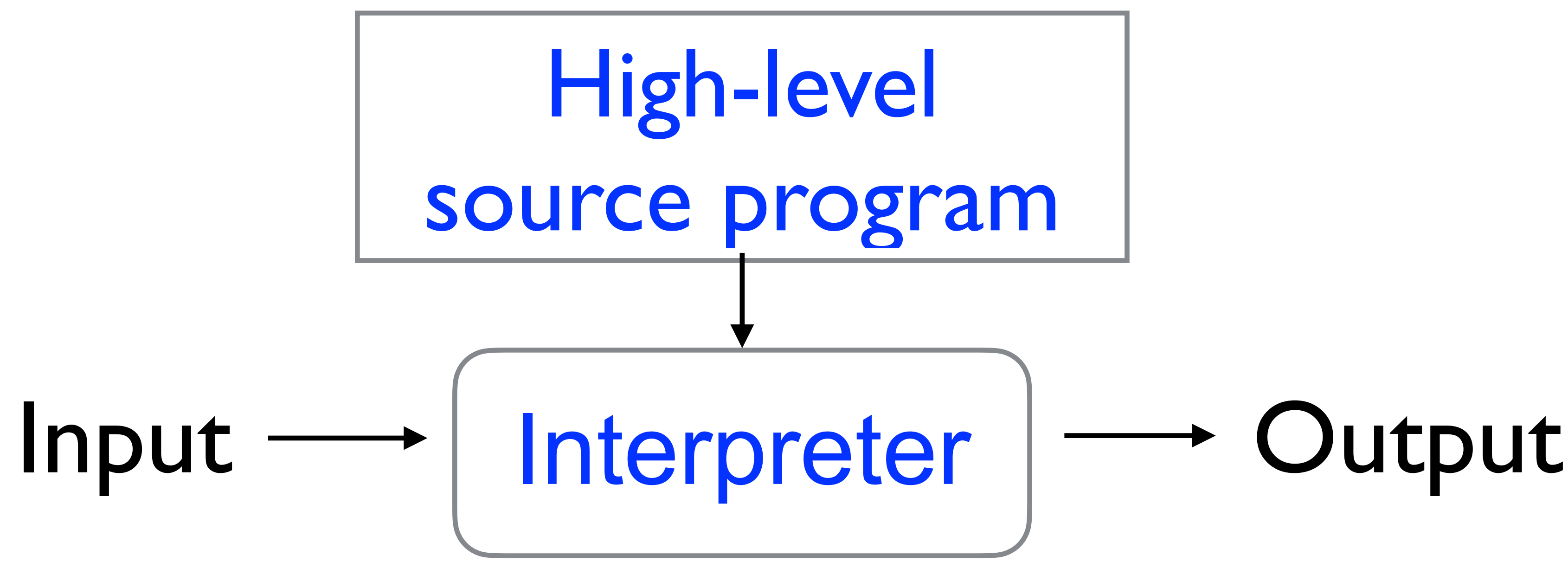
How do we bridge the gap?

- Two classic approaches:
  - A compiler translates high-level language programs into a lower-level language (e.g. machine code)



How do we bridge the gap?

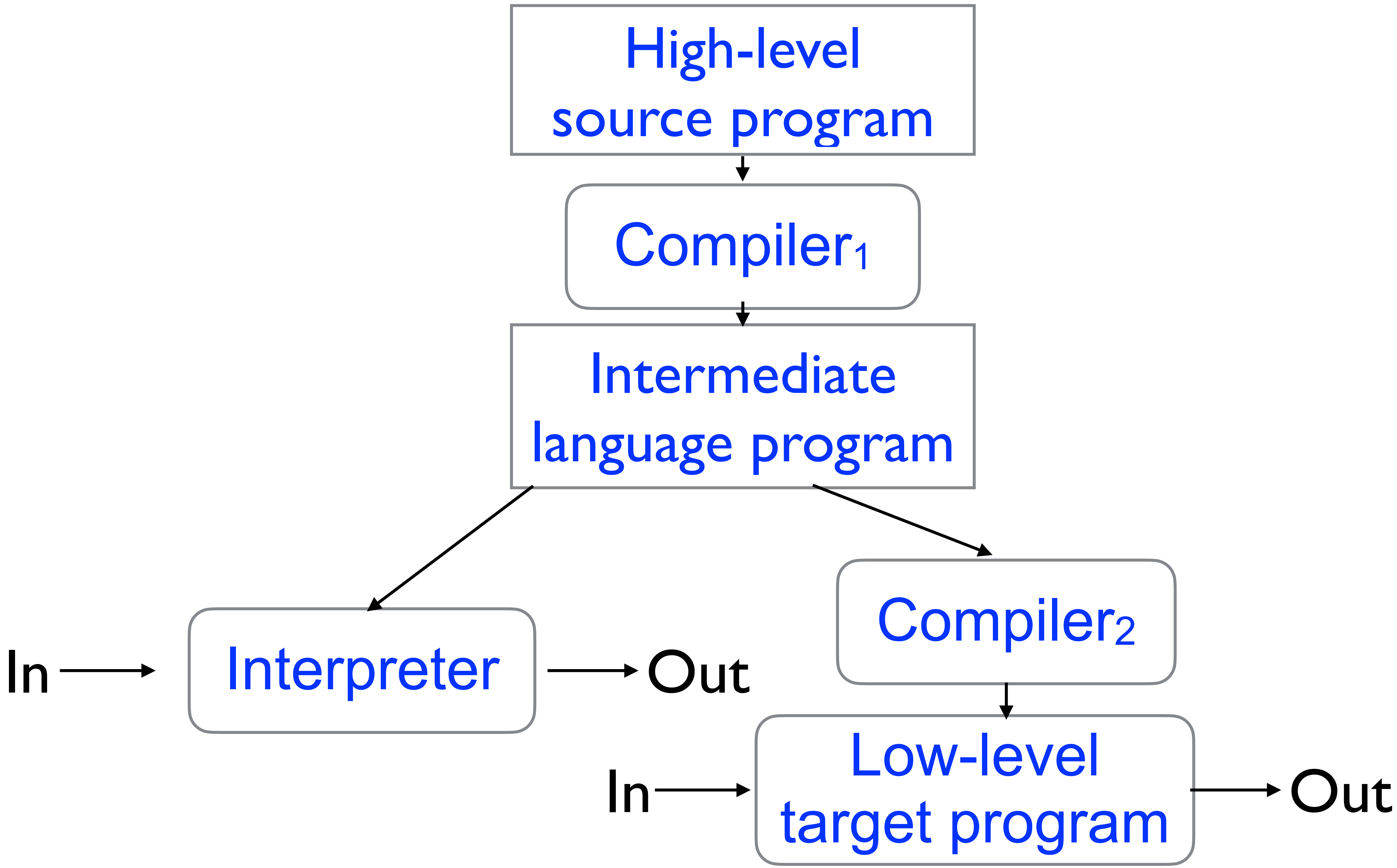
- Two classic approaches:
  - An interpreter is a fixed program that reads in (the representation of) an arbitrary high-level program and executes it



How do we bridge the gap?

- Two classic approaches:
  - A compiler translates high-level language programs into a lower-level language (e.g. machine code)
  - An interpreter is a fixed program that reads in (the representation of) an arbitrary high-level program and executes it
- Compilers can generate code that runs much faster than interpreted code
- Interpreters are quicker and easier to write, maintain and understand

Combined approaches



Stack machines: an intermediate language

- A stack machine is a simple architecture based on a stack of operand values
  - Each machine instruction pops its operands from the stack and pushes its result back on
  - So instructions are very simple, because there's no need to specify operand locations
- Often used in abstract machines, such as the Java Virtual Machine (which Scala also uses)
  - Often compile from high-level language to stack machine byte code which is then interpreted (or perhaps further compiled to machine code)

Stack machine instructions

Instruction set for a very simple stack machine

Instruction	Stack before	Stack after	Side effects
CONST i	$s_1 \ldots s_n$	$i\ s_1 \ldots s_n$	-
LOAD x	$s_1 \ldots s_n$	$Vars[x]\ s_1 \ldots s_n$	-
STORE x	$s_1 \ldots s_n$	$s_2 \ldots s_n$	$Vars[x] := s_1$
PLUS	$s_1\ s_2\ s_3 \ldots s_n$	$(s_2+s_1)\ s_3 \ldots s_n$	-
MINUS	$s_1\ s_2\ s_3 \ldots s_n$	$(s_2-s_1)\ s_3 \ldots s_n$	-

Here `Vars[]` is an auxiliary array mapping variables to values.

Stack machine example

Here's a stack machine program corresponding to the simple statement `c=3-a+(b-7)`

Code
CONST 3
LOAD a
MINUS
LOAD b
CONST 7
MINUS
PLUS
STORE c

Stack		Vars[]
		a=100, b=200
3		a=100, b=200
100 3		a=100, b=200
-97		a=100, b=200
200 -97		a=100, b=200
7 200 -97		a=100, b=200
193 -97		a=100, b=200
96		a=100, b=200
		a=100, b=200,c=96

Stack machine example

Here's a stack machine program corresponding to the simple statement `c=3-a+(b-7)`

CONST 3
LOAD a
MINUS
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STORE c

Is this code sequence unique?

Observe that high-level expressions are more flexible than machine code

Other themes in the study of programming languages

Paradigms

- Imperative
- Object-oriented
- Functional
- Logic
- Concurrent/Parallel
- Scripting

Language Design Criteria

- Expressiveness
- Efficiency
- Correctness

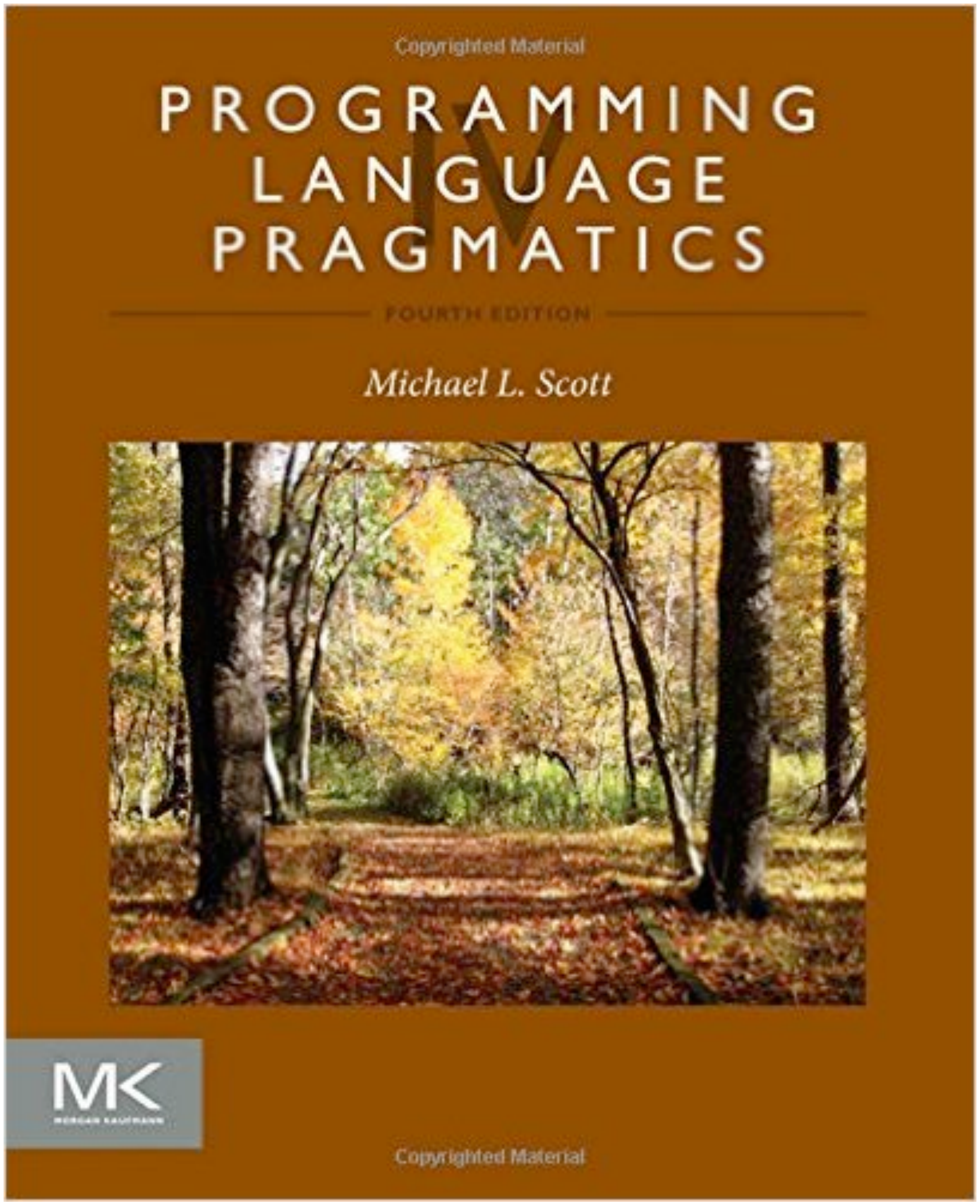
Scale

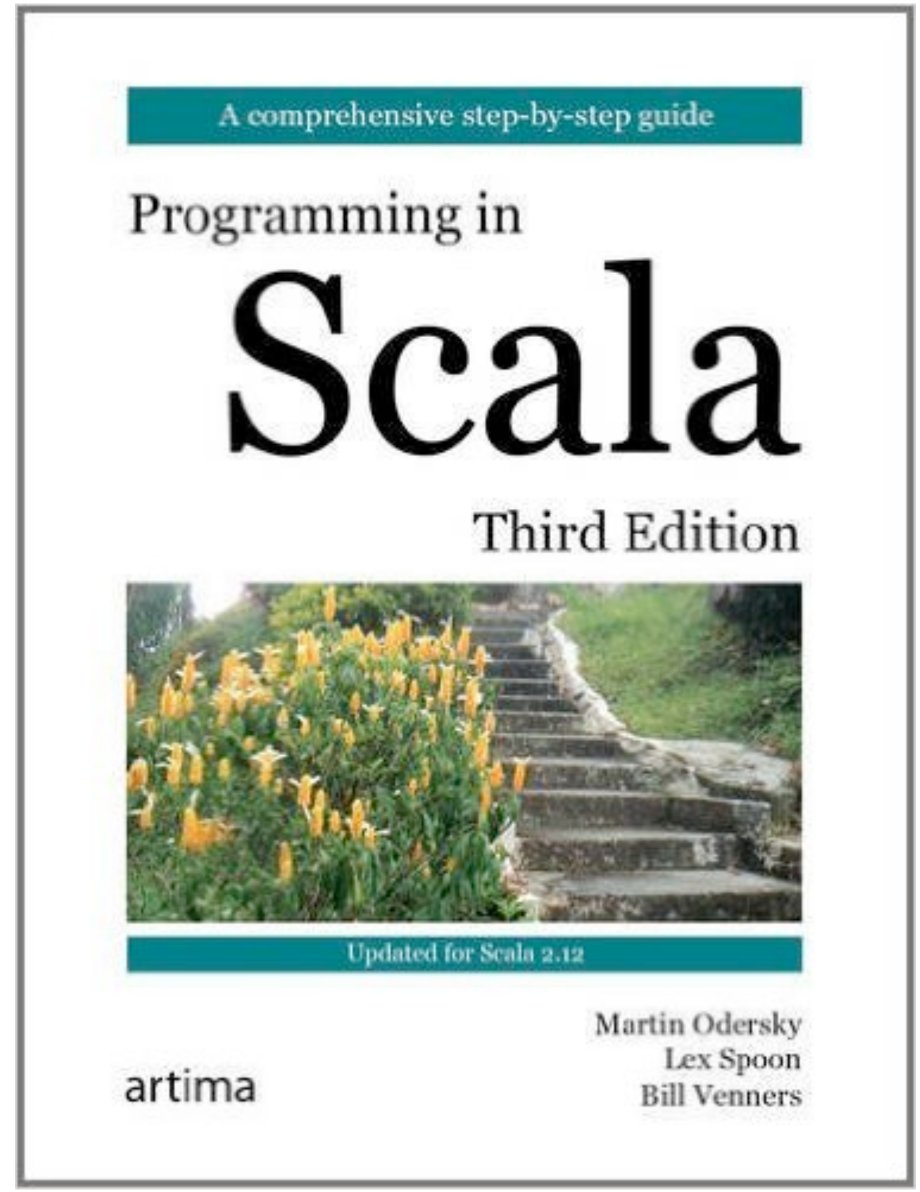
- "Programming in the Small"
  - what's important for 10^2 lines?
- "Programming in the Large"
  - what's important for 10^6 lines?

Course Structure

- Twice-per-week course lectures, live and on Zoom
    - Post-class self-study questions (not to hand in)
- Regular reading assignments
    - Short on-line quiz each day reading is due
- Weekly lab assignments
    - (Mostly) working with interpreters for “toy” languages that illustrate important language features
    - Implementation in Scala
    - You are **encouraged** to work collaboratively on these assignments (but everyone must submit separately)
- In-class midterm and final
- Overall homework load should be ≦10 hours/week

Books





First edition is available free on line, and is good enough for us.

Grading

- 5% Reading Quizzes
- 45% Weekly Labs
- 20% Midterm (Oct. 26)
- 30% Final exam (Dec. 5)
- Two one-on-one Zoom meetings with instructor are required to pass course

WebLab

TU Delft Delft University of Technology

- Web-based system for assignments
  - Lab assignments (and reading quizzes) are issued
  - You develop solutions in the embedded editor
    - (or in your preferred stand-alone environment)
  - You test your solutions against your own tests and against (secret) tests we provide
  - <u>*We can help you debug problems via “discussions”*</u>
  - You submit your solutions
  - Your scores are automatically recorded
  - We (usually) publish correct solutions

One-on-one Zoom meetings

- Two required meetings with instructor
  - Introductory meeting in first two weeks
  - Second meeting after midterm exam
- About 10 minutes each (15 minute slots)
- Sign-up schedule on course web page
- If these are problematic due to scheduling, technological, or other issues, let instructor know

What to do now:

- 1. Do post-class self-study questions
    - They can be found on course web page
- 2. Register to use WebLab
    - See instructions in syllabus
- 3. Do the assigned reading (Scott 1, 2.1, 6.1) and complete the quiz before Thursday at 4pm
    - Quiz can be found inside WebLab
- 4. Start working on the first week's homework assignment, which is due next Tuesday at 4pm
    - The assignment can be found inside WebLab
- 5. Sign up for first one-on-one Zoom meeting with instructor
    - Sign-up schedule is on course web page