Programming Paradigms

Introduction

Prof. Dr. Michael Pradel

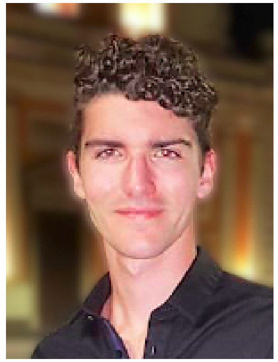
Software Lab, University of Stuttgart

Summer 2023

About Me: Michael Pradel

- **Since 9/2019: Full Professor at University of Stuttgart**
- **Before**
  - Studies at TU Dresden, ECP (Paris), and EPFL (Lausanne)
  - PhD at ETH Zurich, Switzerland
  - Postdoctoral researcher at UC Berkeley, USA
  - Assistant Professor at TU Darmstadt
  - Sabbatical at Facebook, Menlo Park, USA

About the Software Lab

- **My research group since 2014**
- **Focus: Tools and techniques for building reliable, efficient, and secure software**
  - Program testing and analysis
  - Machine learning, security
- **Thesis and job opportunities**

Overview

- **Motivation** ←
  - What the course is about
  - Why it is interesting
  - How it can help you
- **Organization**
  - Exercises
  - Grading
- **Introduction**
  - Programming languages:
    History, paradigms, compilation, interpretation

The Role of Programming

- **Programming: Essential form of expression for a computer scientist**
  - ”The limits of my language mean the limits of my world.” (Ludwig Wittgenstein)
- **Programming languages determine what algorithms and ideas you can express**

Goal of this Course

Understand how programming languages (PLs) work

- How are languages defined?
- What language design choices exist?
- What language features could I use?
- How are languages implemented?

Why Learn About PLs?

Enables you to

- choose the right PL for a specific purpose
- choose among alternative ways to express things
- make best use of tools (e.g., debuggers, IDEs, analysis tools)
- understand obscure language features
- simulate useful features in languages that lack them

Concepts vs. Languages

This course is not about

- All details of a specific language
- A systematic walk through a set of languages

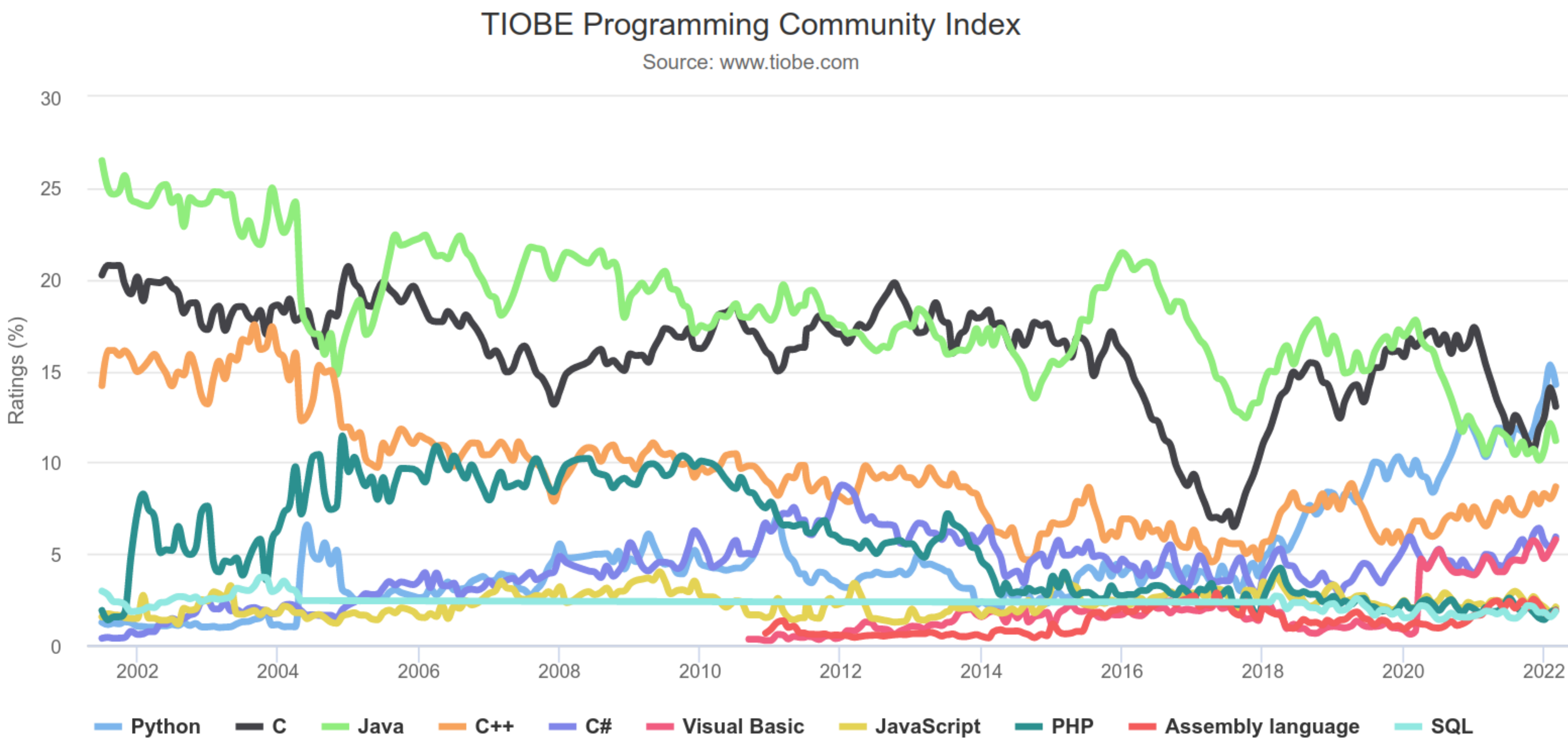
Instead, this course is about

- Concepts underlying many languages
- Various languages as examples

Isn't Knowing {Pick a PL} Enough?

- **Complex systems:**
  Built in various languages
  - E.g., Facebook/Meta: Wild mix of languages covering various language paradigms
- **New languages arrive regularly (and old ones fade away)**

Isn’t Knowing {Pick a PL} Enough?



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Language

- Written material (slides, exercises): English
- Lectures: German
- Exercise discussions: English
- Final exam: Questions in English, answers in German or English

Schedule

Three weekly slots:

Mon, Wed, Fri, all 11:30am

- But: Not all slots used
- See course page for schedule:

  http://software-lab.org/teaching/summer2023/pp/

Lectures

Slides, hand-written notes, etc:

- Made available shortly after each lecture

Lecture videos:

- Old videos available on course page
- This year’s lectures will be recorded
- Recommendation: Use for exam preparation, not as replacement for live lectures

Exercises

- **Six graded exercises**
- **We publish on day X**
  - On the course page
- **You submit your solution by day X+7**
  - Via Ilias
- **Discussion of exercises after day X+7**
  - One discussion session for the entire course

Ilias

Platform for discussions, in-class quizzes, and sharing additional material

- Please register for the course
- Use it for all questions related to the course
- Messages sent to all students go via Ilias

Link to Ilias course on
software-lab.org/teaching/summer2023/pp/

Quizzes During the Lectures

- **A few quizzes during each lecture**
  - Check your understanding
  - Access quizzes via Ilias
- **Up to two bonus points for the final exam**
  - Partial points for answering at all
  - Full points for correct answers

Questions and Discussions

For any (non-personal) questions:

Use forum in Ilias

- Preferred language: English
- Answering each other is encouraged
- Teaching assistants and me are monitoring it

Grading

- **Exercises: Passing is prerequisite for final exam ("Schein")**
  - Six exercises
  - Each exercise: 100 points
  - Needed to pass:
    - At least 30 points in five exercises
    - At least 360 total points
  - If at least 30 points in all six exercises: One bonus point for the final exam
  - Your points: Published after each exercise

Final Exam

- **Final exam: Open book**
  - All printed and hand-written material allowed (incl. slides, textbooks, and a dictionary)
  - Tests your understanding, not your knowledge

Plagiarism and Cheating

- **Exercises are individual**
- **Any form of cheating and plagiarism**
  - Treated like cheating in an exam
  - I.e., failing the ”Schein”
- **Cheating includes**
  - Showing your solution to others
  - Working together in a solution
  - Using a solution from someone else
  - Using a solution suggested by an AI tool

Reading Material

- **Most relevant book:**
  Programming Language Pragmatics
  by Michael L. Scott
- **Also interesting:**
  Concepts of Programming Languages
  by Robert W. Sebesta
- **Pointers to book chapters and web resources: Course page**

Some Statistics (Summer 2022)

- 80/115 students who submitted ≥ 1 exercise(s) got the "Schein"
- 80/91 students who submitted ≥ 3 exercise(s) got the "Schein"
- Of those students who got the "Schein", only 4/79 failed the final exam

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Don't give up too early!

The "Schein" prepares well for the exam.

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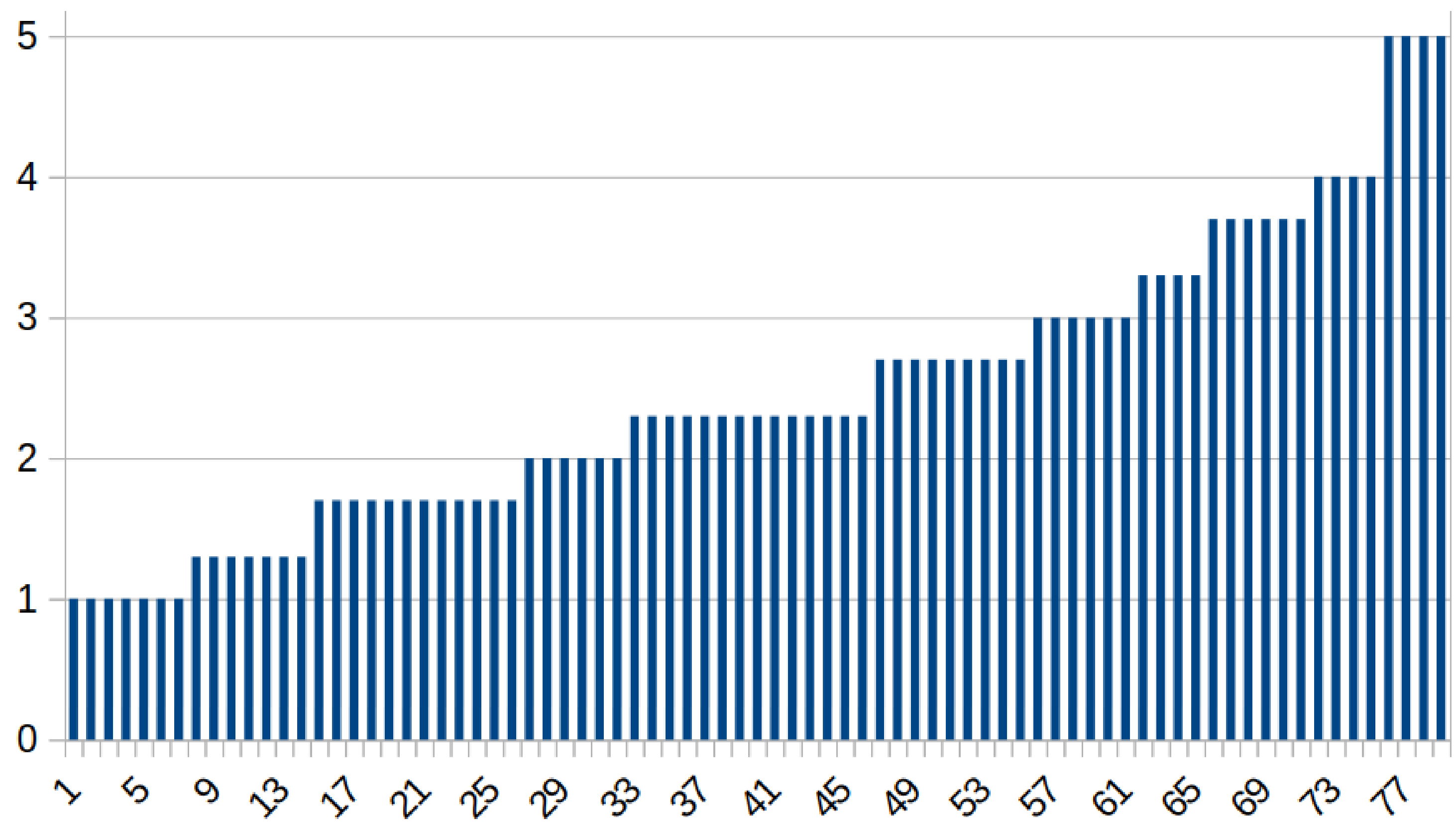
Exam grades:



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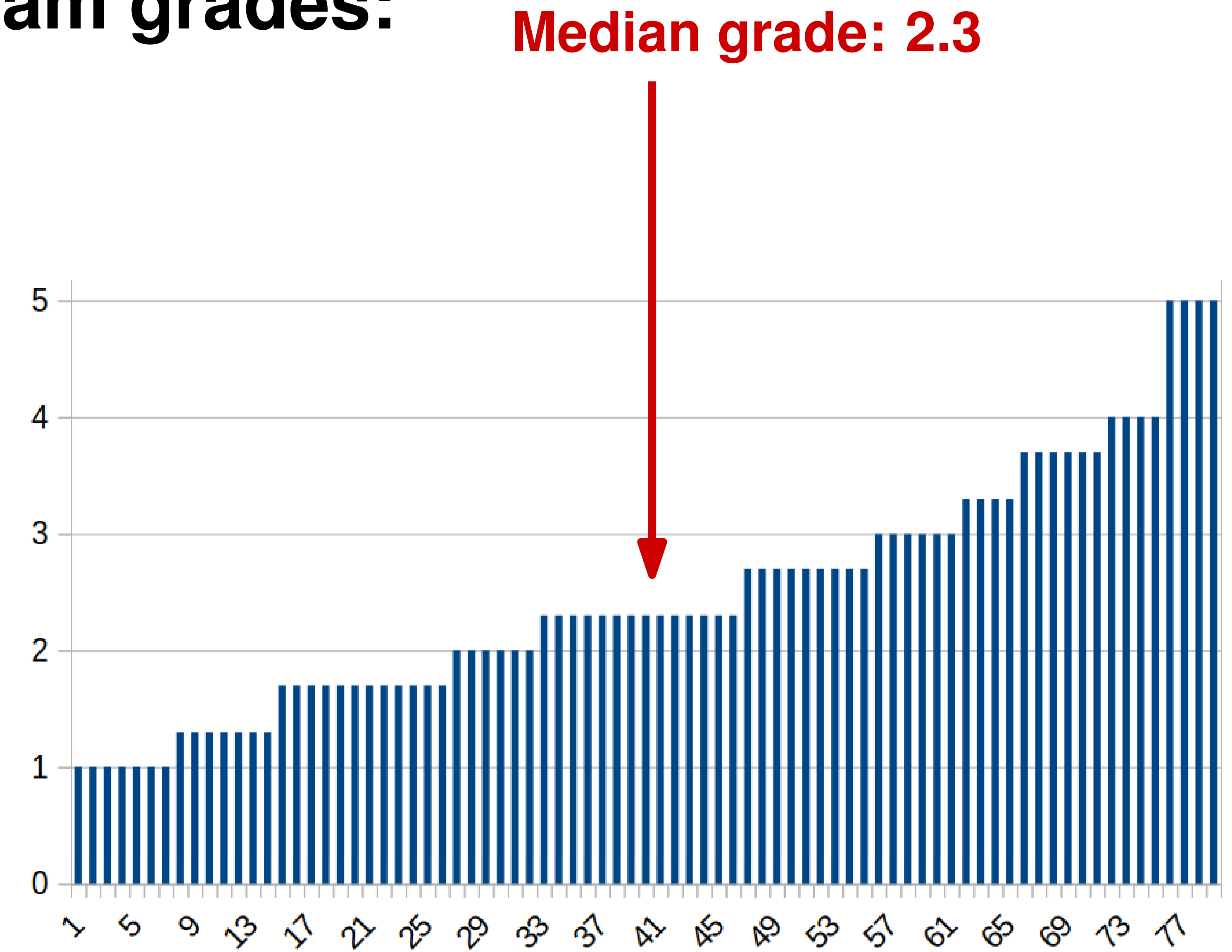


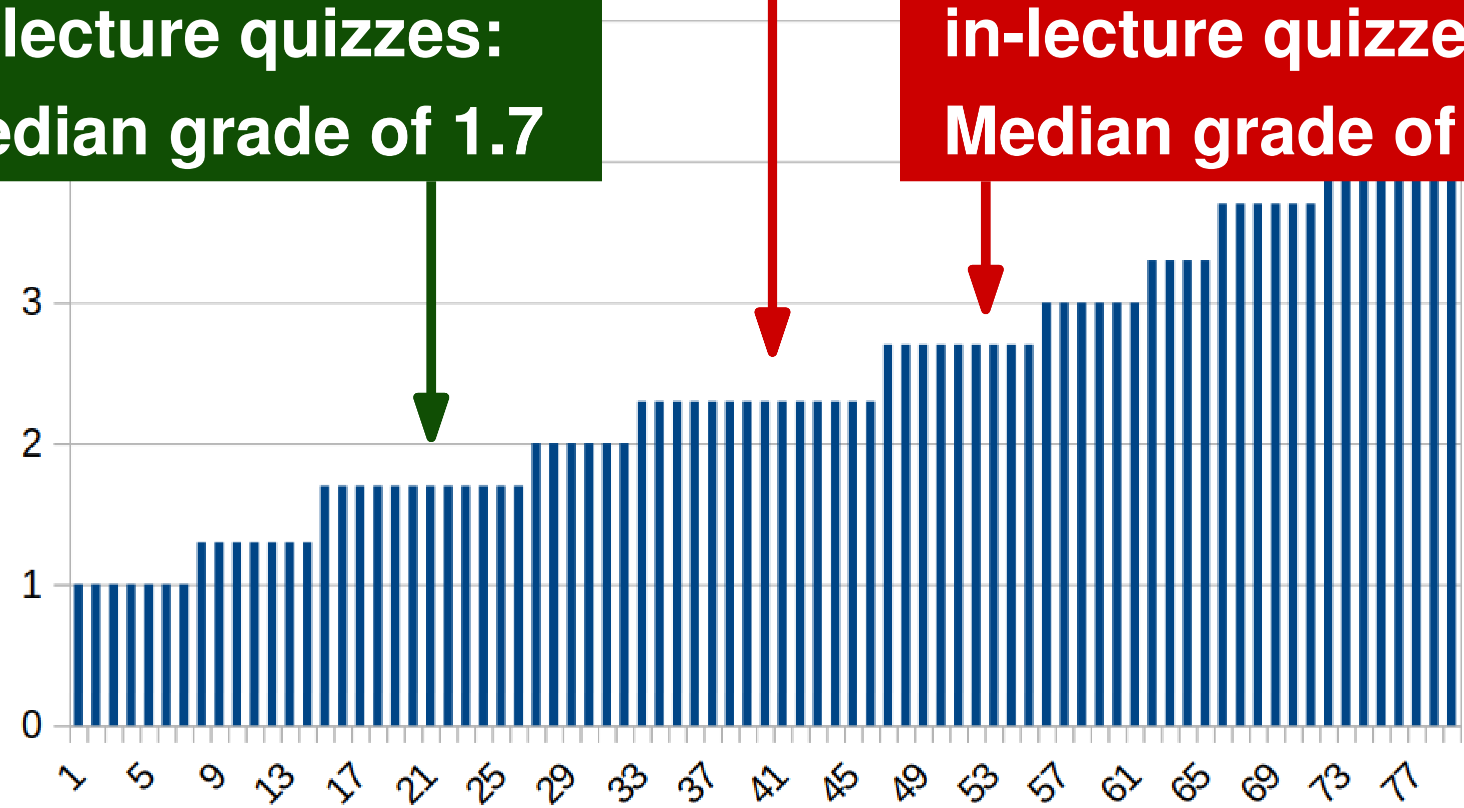
Some Statistics (Summer 2022)

Exam grades:

Median grade: 2.3

Students with two bonus points from in-lecture quizzes: Median grade of 1.7

Students with zero bonus points from in-lecture quizzes: Median grade of 2.7



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History: From Bits ...

First electronic computers: Programmed in machine language

- Sequence of bits
- Example: Calculate greatest common divisor

```
55 89 e5 53  83 ec 04 83  e4 f0 e8 31  00 00 00 89  c3 e8 2a 00
00 00 39 c3  74 10 8d b6  00 00 00 00  39 c3 7e 13  29 c3 39 c3
75 f6 89 1c  24 e8 6e 00  00 00 8b 5d  fc c9 c3 29  d8 eb eb 90
```

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```

Machine time more valuable than developer time

... over Assembly ...

Human-readable abbreviations for machine language instructions

- Less error-prone, but still very machine-centered
- Each new machine: Different assembly language
- Developer thinks in terms of low-level operations

... over Assembly ...

Greatest common divisor in x86:

```
    pushl   %ebp
    movl    %esp, %ebp
    pushl   %ebx
    subl    $4, %esp
    andl    $-16, %esp
    call    getint
    movl    %eax, %ebx
    call    getint
    cmpl    %eax, %ebx
    je      C
A:  cmpl    %eax, %ebx
    jle     D
    subl    %eax, %ebx
B:  cmpl    %eax, %ebx
    jne     A
C:  movl    %ebx, (%esp)
    call    putint
    movl    -4(%ebp), %ebx
    leave
    ret
D:  subl    %ebx, %eax
    jmp     B
```

... to High-level Languages

- **1950s: First high-level languages**
  - Fortran, Lisp, Algol
- **Developer thinks in mathematical and logical abstractions**

... to High-level Languages

Greatest common divisor in Fortran:

```
subroutine gcd_iter(value, u, v)
  integer, intent(out) :: value
  integer, intent(inout) :: u, v
  integer :: t

  do while( v /= 0 )
     t = u
     u = v
     v = mod(t, v)
  enddo
  value = abs(u)
end subroutine gcd_iter
```

Today: 1000s of Languages

- **New languages gain traction regularly**
- **Some long-term survivors**
  - Fortran, Cobol, C

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Poll:

Your favorite programming language?

See LiveVoting in Ilias

What Makes a PL Successful?

- **Expressive power**
  - But: All PLs are Turing-complete
- **Ease of learning (e.g., Basic, Python)**
- **Open source**
- **Standardization: Ensure portability across platforms**
- **Excellent compilers**
- **Economics**
  - E.g., C# by Microsoft, Objective-C by Apple

PL Spectrum

- **Broad classification**
  - Declarative ("what to compute"):
    E.g., Haskell, SQL, spreadsheets
  - Imperative ("how to compute it"):
    E.g., C, Java, Perl
- **Various PL paradigms:**

Sequential

Functional

Statically typed

Dynamically typed

Shared-memory parallel

Distributed-memory parallel

Logic

Dataflow

- **Most languages combine multiple paradigms**

Example: Imperative PL

C implementation for GCD:

```
int gcd(int a, int b) {
  while (a != b) {
    if (a > b) a = a - b;
    else b = b - a;
  }
  return a;
}
```

Example: Imperative PL

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Statements that influence subsequent statements

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Statements that influence subsequent statements

Assignments with side effect of changing memory

Example: Functional PL

OCaml implementation of GCD

```
let rec gcd a b =
  if a = b then a
  else if a > b then gcd b (a - b)
       else gcd a (b - a)
```

Example: Functional PL

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Recursive function with two arguments

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Recursive function with two arguments

Focus on mathematical relationship between inputs and outputs

Example: Logic PL

Prolog implementation of GCD

```
gcd(A,B,G) :- A = B, G = A.
gcd(A,B,G) :- A > B, C is A-B, gcd(C,B,G).
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Facts and rules

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Facts and rules

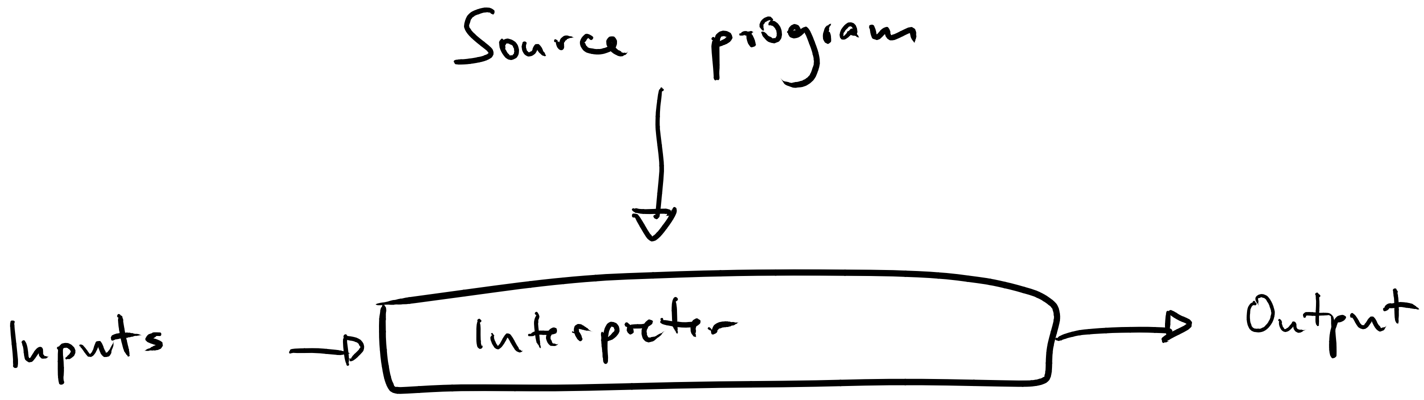
Focus on logical relationships between variables

Compilation and Interpretation

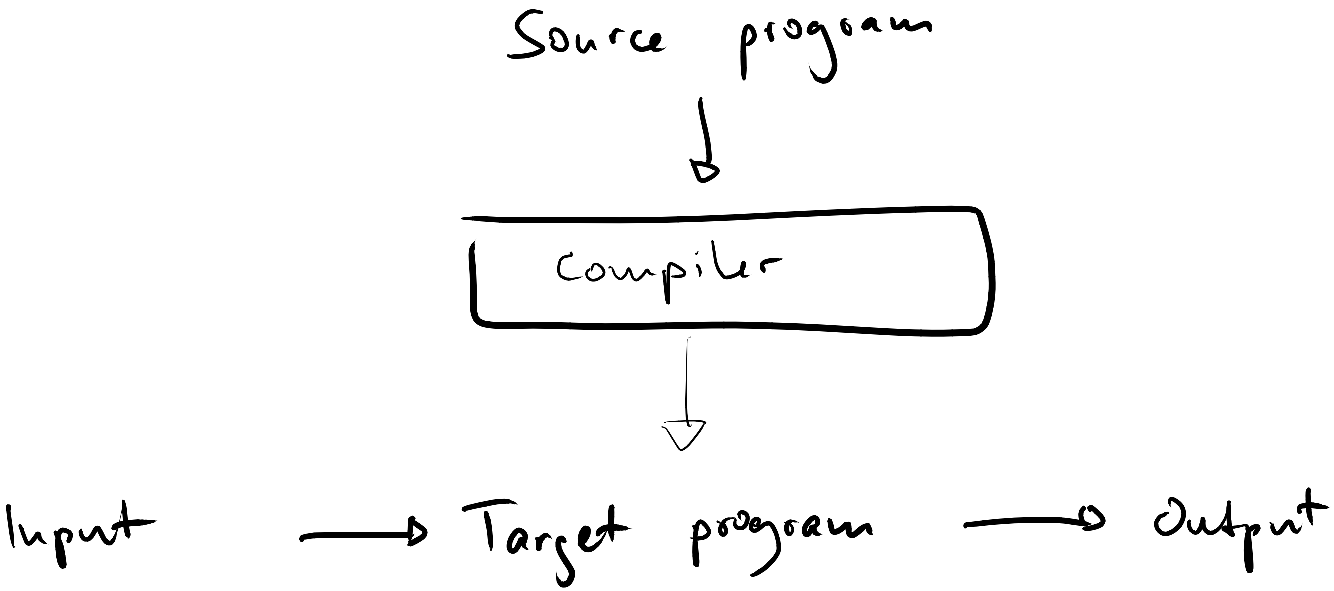
Different ways of executing a program

- Pure interpretation
- Pure compilation (e.g., C)
- Mixing compilation and interpretation
  - Compile to bytecode and immediately interpret it (e.g., Python)
  - Virtual machine with just-in-time compilation (e.g., Java)

Interpreter

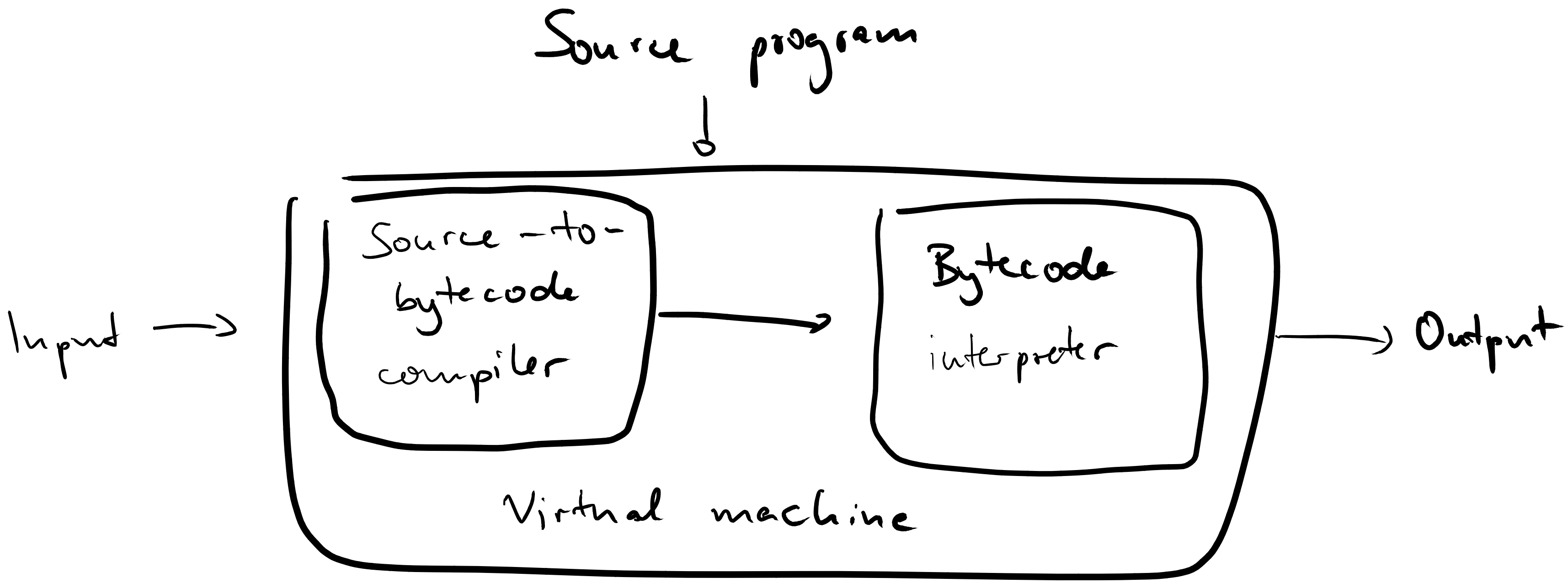


Compiler

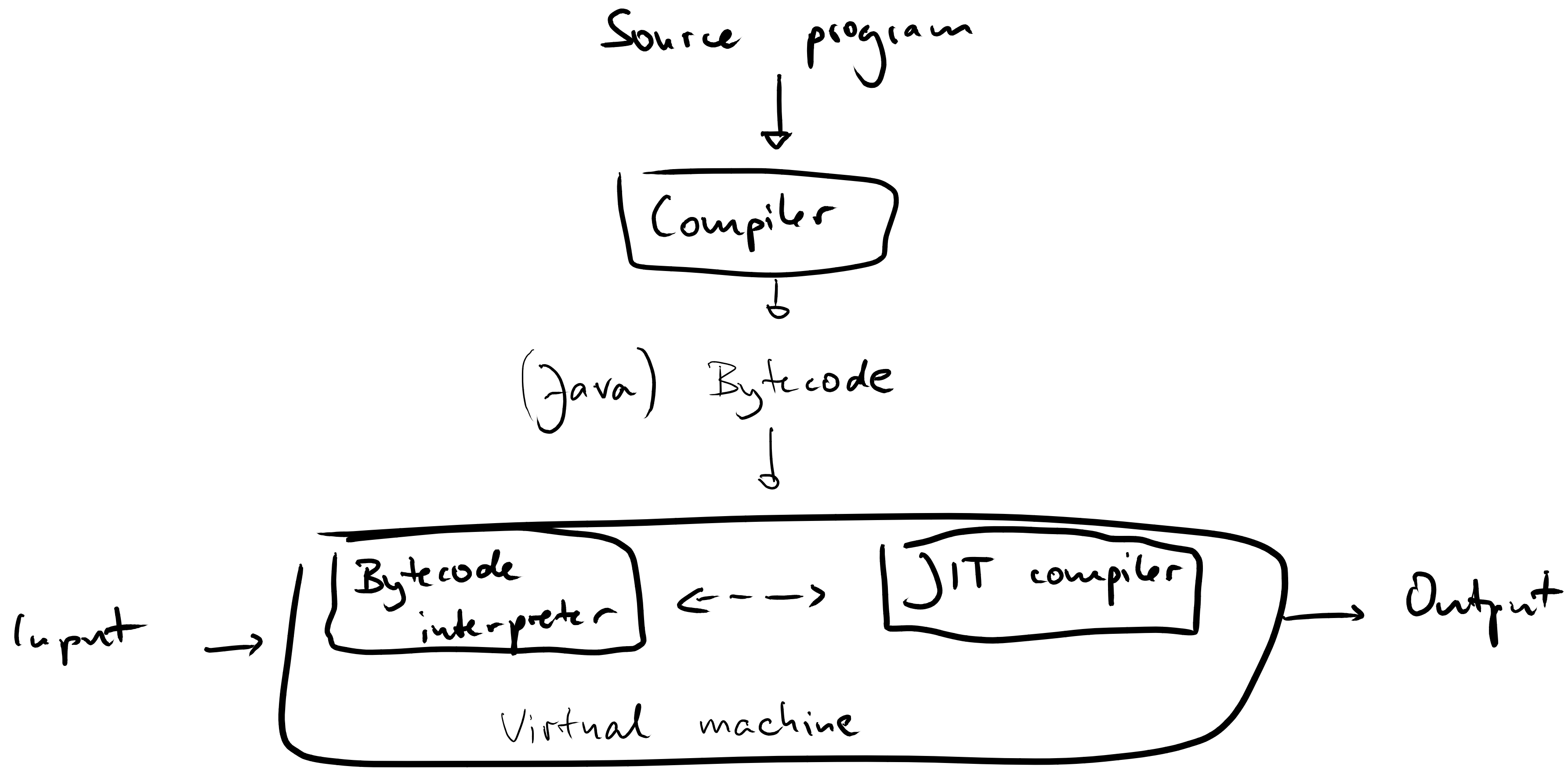


Compile to Bytecode & Interpret Immediately

↳ E.g. Python



Virtual Machine + Just-In-Compilation



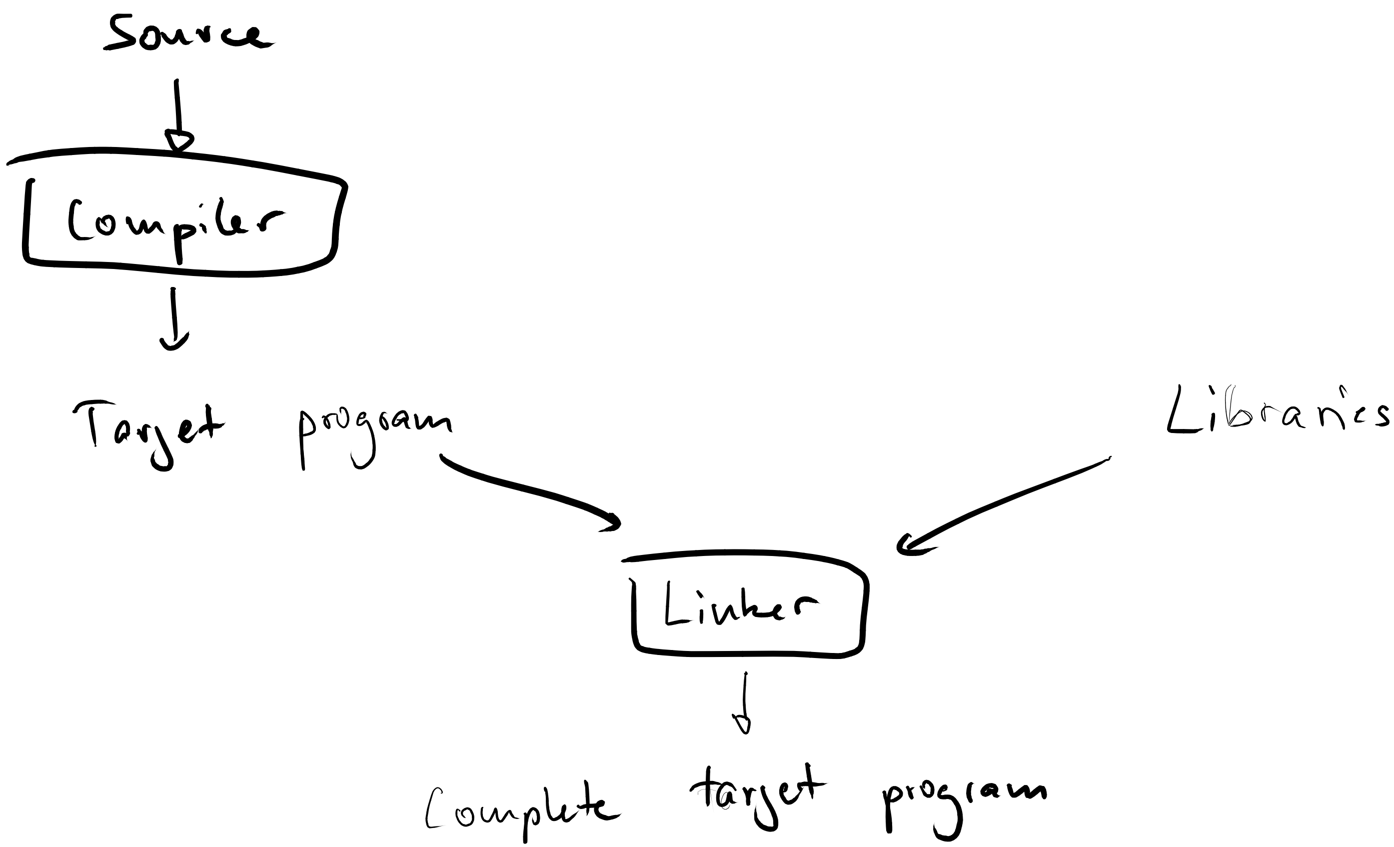
PL Design vs. Implementation

- **Some PLs are easier to compile than others**
- **E.g., runtime code generation**
  - Code to execute: Unknown at compile time
  - Hard to compile
  - Easy to interpret

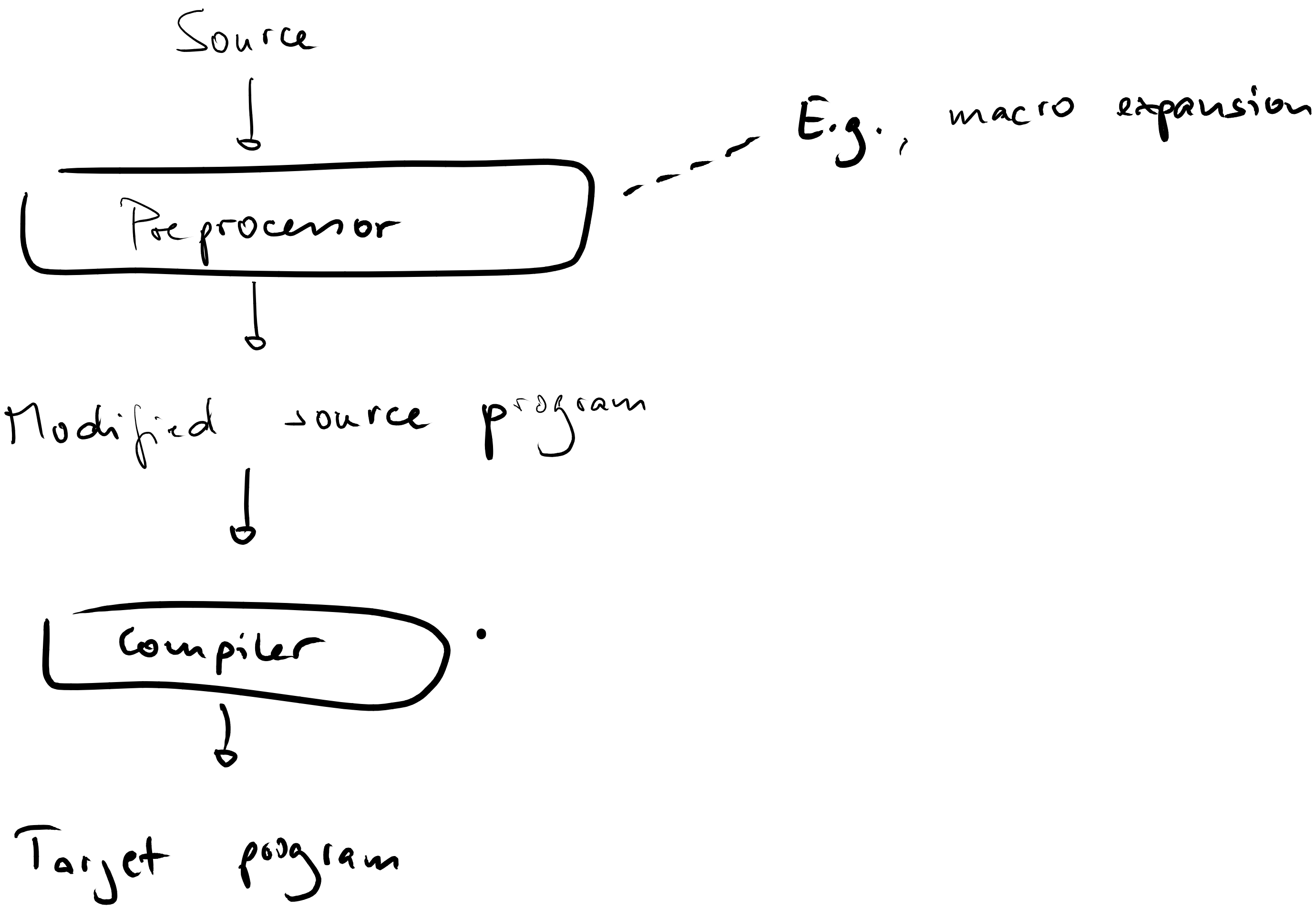
Other Tools

- Linkers
- Preprocessors
- Source-to-source compilers

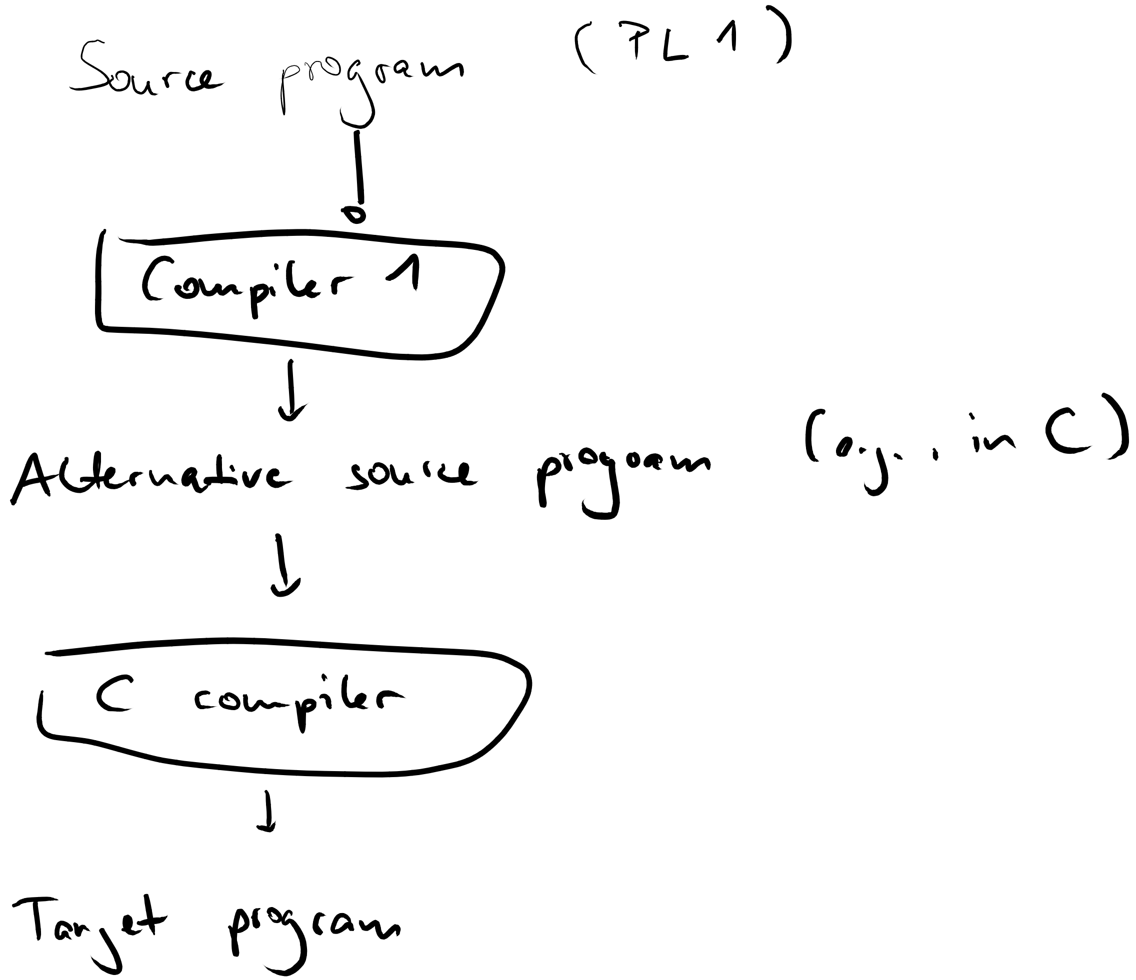
Linker


Source
Compiler
Target program
Libraries
Linker
Complete target program

Preprocessors



Source-to-source compiler



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