CSCI312 Principles of Programming Languages

Chapter 1

Overview

Xu Liu

What is a Programming Language (PL)

Notation for

- *Describing a computation that is machine-translatable (and human-readable)*
- *Is capable of expressing any computer program*

Why need so many PLs

- *Same theoretical power*
- *Different practical power*
- *Facilitate or impede certain modes of thought*

What We will Learn

- Various paradigms for specifying programs
- How to give (precise) meaning to programs
- How to use programming languages to prevent runtime errors
- Explore these concepts in real-world languages

Why Study PLs?

Help choose a language

- *C vs. Modula-3 vs. C++ for system programming*
- *Fortran vs. APL vs. Ada for numerical computations*
- *Ada vs. Modula-2 for embedded systems*
- *Common Lisp vs. Scheme vs. ML for symbolic data manipulations*
- *Java vs. C/CORBA for networked PC programs*

Why Study PLs?

Make It Easier to Learn New Languages

- *similar syntax/semantics for languages*
    - iteration, recursion, abstraction, function call, …

Why Study PLs?

Help Make Better Use of Whatever Language You Use

- *Understand obscure features*
  - In C, help understand unions, arrays, pointers, separate compilation, varargs, catch and throw
  - In Common Lisp, help understand first-class functions/closures, streams, catch and throw, symbol internals
- *Understand implementation costs*
  - Use simple arithmetic equal (x*x instead of x**2)
  - Avoid call by value with large data sets

Course Administration

- Instructor: Xu Liu (McGl 117; xliu13@wm.edu)
  - *Office hours: 11am-12:00pm MWF*
- TA: Jialiang Tan (jtan02@email.wm.edu)
  - *Office hours: see webpage below*
- Most contents are on
  - *http://www.cs.wm.edu/~xl10/cs312*
- Assignment submissions and grades are on Blackboard

Textbooks

- Required: None
- Recommended
  - *Tucker and Noonan. Programming Languages: Principles and Paradigms. 2006.*
  - *Scott. Programming Languages Pragmatics. (fourth edition) 2016.*

Course Requirements

- A project-centric course
  - *six projects*
- Midterm and final exams
- Attendance
  - *in-class quizzes*

Grading

- Breakdown
  - *Projects: 40%*
  - *Midterm: 15%*
  - *Attendance: 10%*
  - *Final: 35%*
- 10% late penalty per day
- Final grade is curved
  - *90% guaranteed A-, 80% B-, etc.*

Collaboration

- Programming assignments
  - *May complete alone or in pairs*
  - *If in pairs, must follow "the rules of pair programming", linked on the course web page*
    - can change your partner for each project, but not during one project
- Any cheating will result in an F and referral to honor code violation committee
- Plagiarism-detection software will be used

Contents

Principles of PL

Programming languages have four properties:

- *Syntax*
- *Naming*
- *Types*
- *Semantics*

For any language:

- *Its designers must define these properties*
- *Its programmers must master these properties*

Syntax

The *syntax* of a programming language is a precise description of all its grammatically correct programs.

When studying syntax, we answer questions like:

- *What are the basic statements for the language?*
- *How do I write a ... ?*
- *Why is this a syntax error?*

Naming

Many entities in a program have names:

variables, types, functions, parameters, classes, objects, …

Named entities are bound in a running program to:

- *Scope*
- *Visibility*
- *Type*
- *Lifetime*

Types

A *type* is a collection of values and a collection of operations on those values.

- Simple types
  - *numbers, characters, booleans, …*
- Structured types
  - *Strings, lists, trees, hash tables, …*
- A language's *type system* can help to:
  - *Determine legal operations*
  - *Detect type errors*

Semantics

The meaning of a program is called its *semantics*.

In studying semantics, we answer questions like:

- *What does each statement mean?*
- *What underlying model governs run-time behavior, such as function call?*
- *How are objects allocated to memory at run-time?*

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1.2 Paradigms

A programming *paradigm* is a pattern of problem-solving thought that underlies a particular genre of programs and languages.

There are four main programming paradigms:

- *Imperative*
- *Object-oriented*
- *Functional*
- *Logic (declarative)*

Imperative Paradigm

Follows the classic von Neumann-Eckert model:

- *Program and data are indistinguishable in memory*
- *Program = a sequence of commands*
- *State = values of all variables when program runs*
- *Large programs use procedural abstraction*

Example imperative languages:

- *Cobol, Fortran, C, Ada, Perl, …*

The von Neumann-Eckert Model

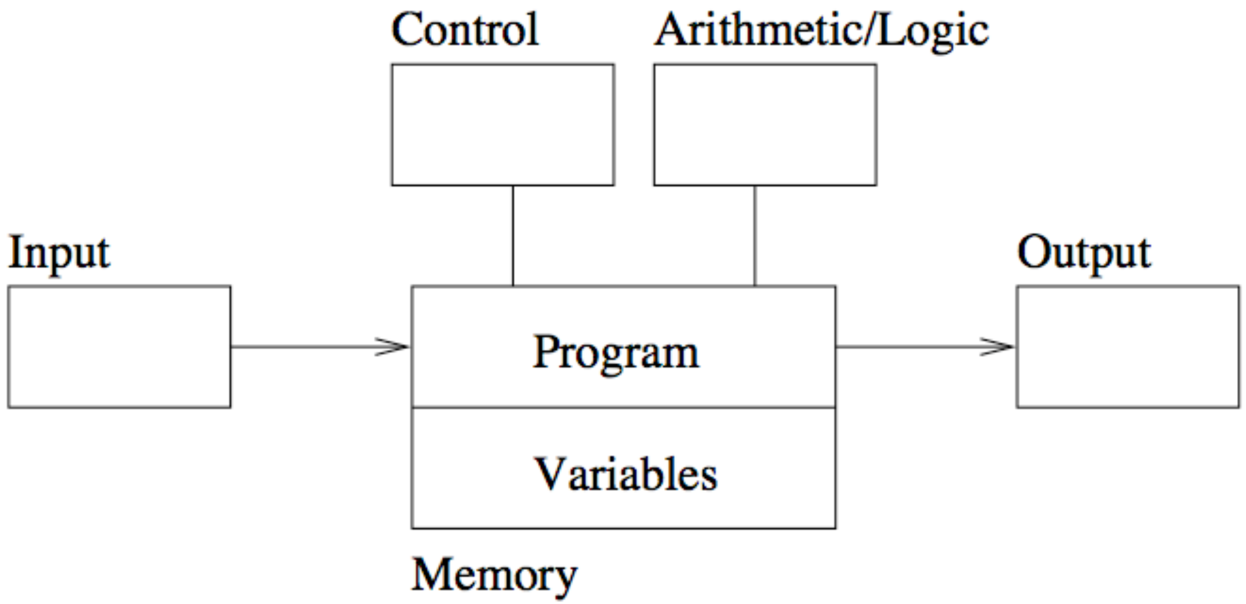


Figure 1.1: The von Neumann-Eckert Computer Model

Object-oriented (OO) Paradigm

An OO Program is a collection of objects that interact by passing messages that transform the state.

When studying OO, we learn about:

- *Sending Messages*
- *Inheritance*
- *Polymorphism*

Example OO languages:

Smalltalk, Java, C++, C#, and Ruby

Functional Paradigm

Functional programming models a computation as a collection of mathematical functions.

- *Input = domain*
- *Output = range*

Functional languages are characterized by:

- *Functional composition*
- *Recursion*

Example functional languages:

- *Lisp, Scheme, ML, Haskell, …*

Logic Paradigm

Logic programming declares what outcome the program should accomplish, rather than how it should be accomplished.

When studying logic programming we see:

- *Programs as sets of constraints on a problem*
- *Programs that achieve all possible solutions*
- *Programs that are nondeterministic*

Example logic programming languages:

- *Prolog*

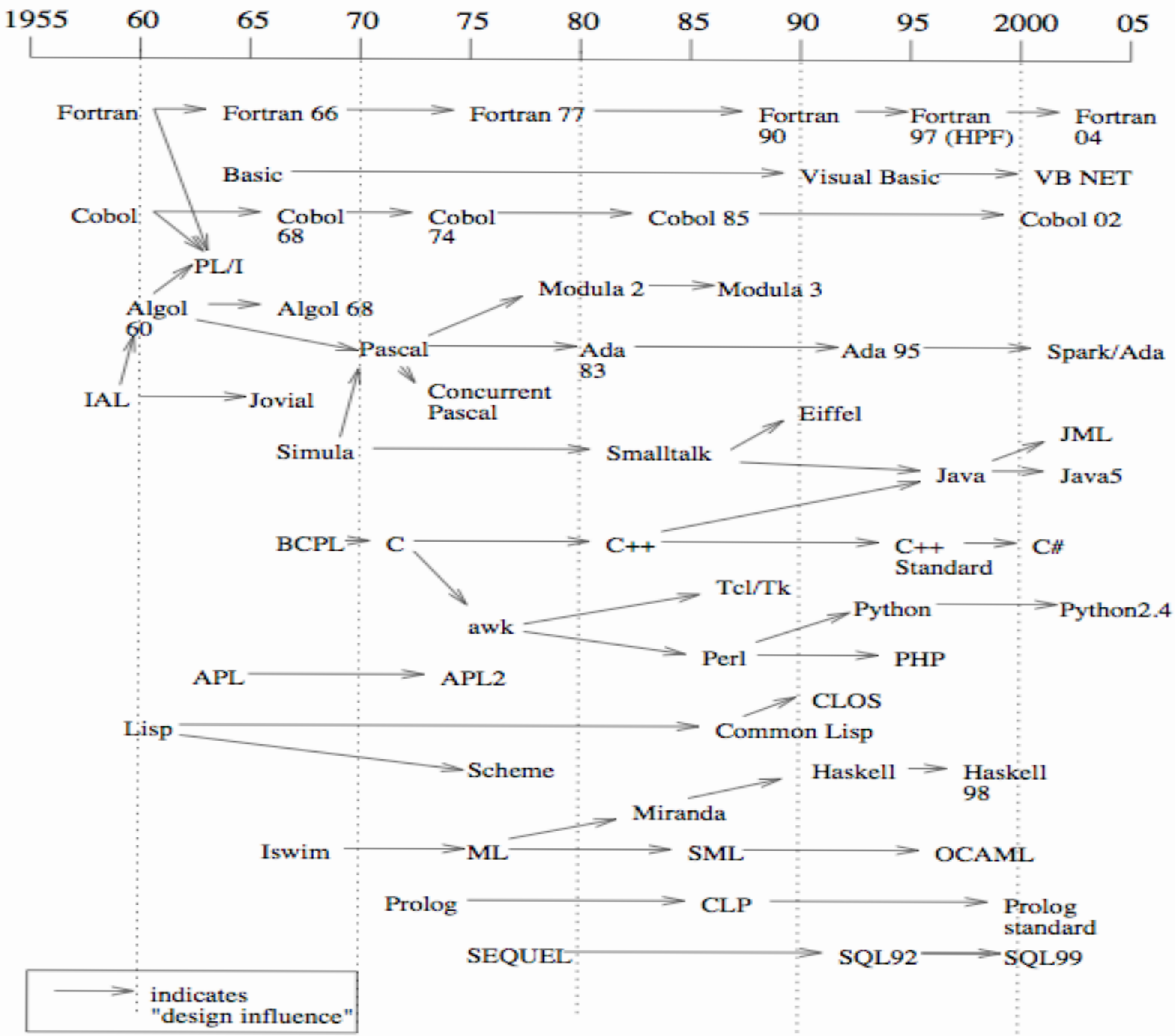


Figure 1.2: A Snapshot of Programming Language History

What makes a successful language?

Key characteristics:

- *Simplicity and readability*
- *Clarity about binding*
- *Reliability*
- *Support*
- *Abstraction*
- *Orthogonality*
- *Efficient implementation*

Simplicity and Readability

- Small instruction set
  - *E.g., Java vs Scheme*
- Simple syntax
  - *E.g., C/C++/Java vs Python*
- Benefits:
  - *Ease of learning*
  - *Ease of programming*

Clarity about Binding

A language element is bound to a property at the time that property is defined for it.

So a *binding* is the association between an object and a property of that object

- *Examples:*
  - a variable and its type
  - a variable and its value
- *Early binding* takes place at compile-time
- *Late binding* takes place at run time

Reliability

A language is *reliable* if:

- *Program behavior is the same on different platforms*
  - E.g., early versions of Fortran
- *Type errors are detected*
  - E.g., C vs Haskell
- *Semantic errors are properly trapped*
  - E.g., C vs C++
- *Memory leaks are prevented*
  - E.g., C vs Java

Language Support

- Accessible (public domain) compilers/interpreters
- Good texts and tutorials
- Wide community of users
- Integrated with development environments (IDEs)

Abstraction in Programming

- Data
  - *Programmer-defined types/classes*
  - *Class libraries*
- Procedural
  - *Programmer-defined functions*
  - *Standard function libraries*

Orthogonality

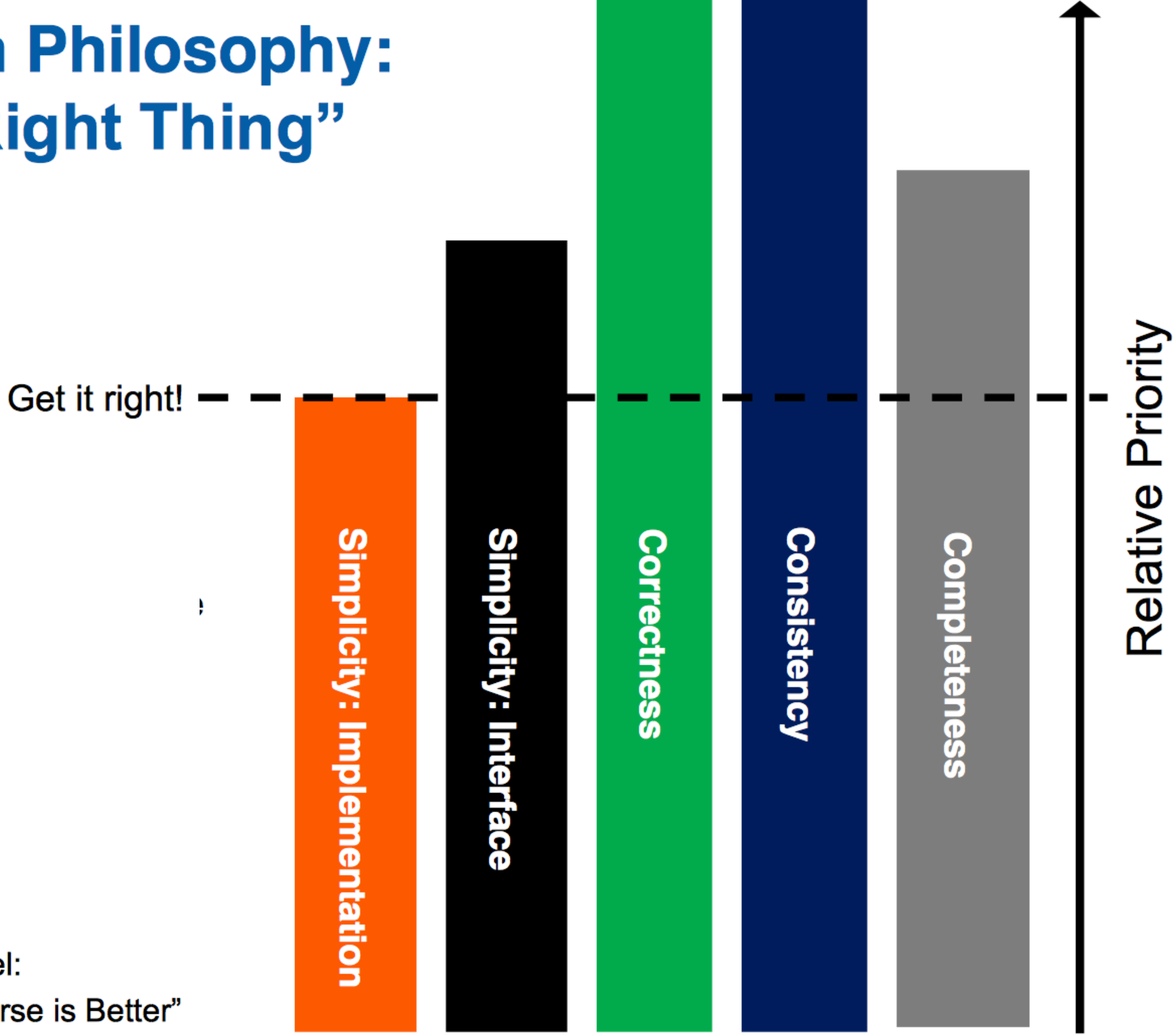
A language is *orthogonal* if its features are built upon a small, mutually independent set of primitive operations.

- Fewer exceptional rules = conceptual simplicity
  - *E.g., restricting types of arguments to a function*
- Tradeoffs with efficiency

Efficient implementation

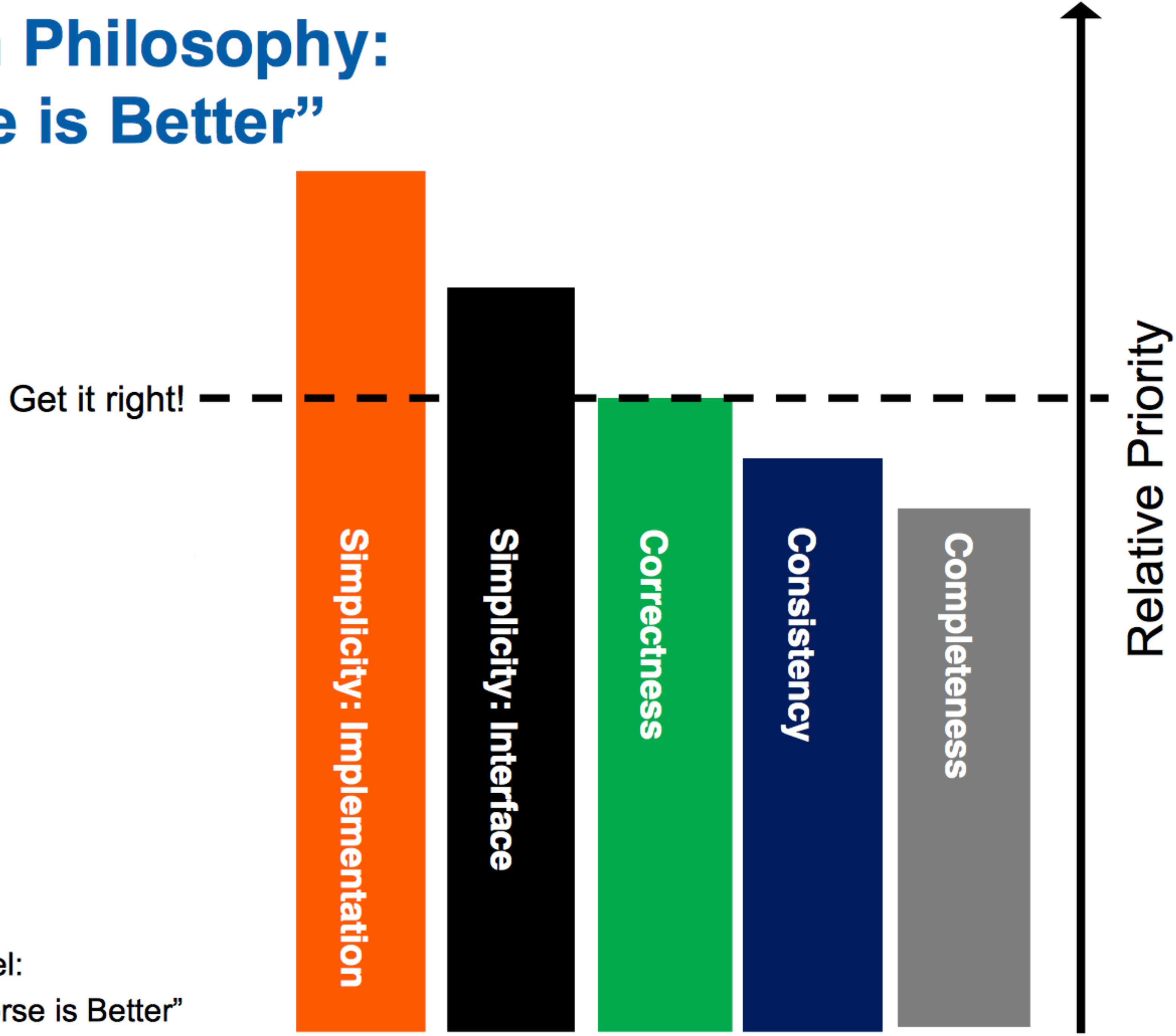
- Embedded systems
  - *Real-time responsiveness (e.g., navigation)*
  - *Failures of early Ada implementations*
- Web applications
  - *Responsiveness to users (e.g., Google search)*
- Corporate database applications
  - *Efficient search and updating*
- AI applications
  - *Modeling human behaviors*

Design Philosophy: “The Right Thing”



Richard Gabriel:
The rise of Worse is Better”
“https://www.jwz.org/doc/worse-is-better.html

Design Philosophy: "Worse is Better"



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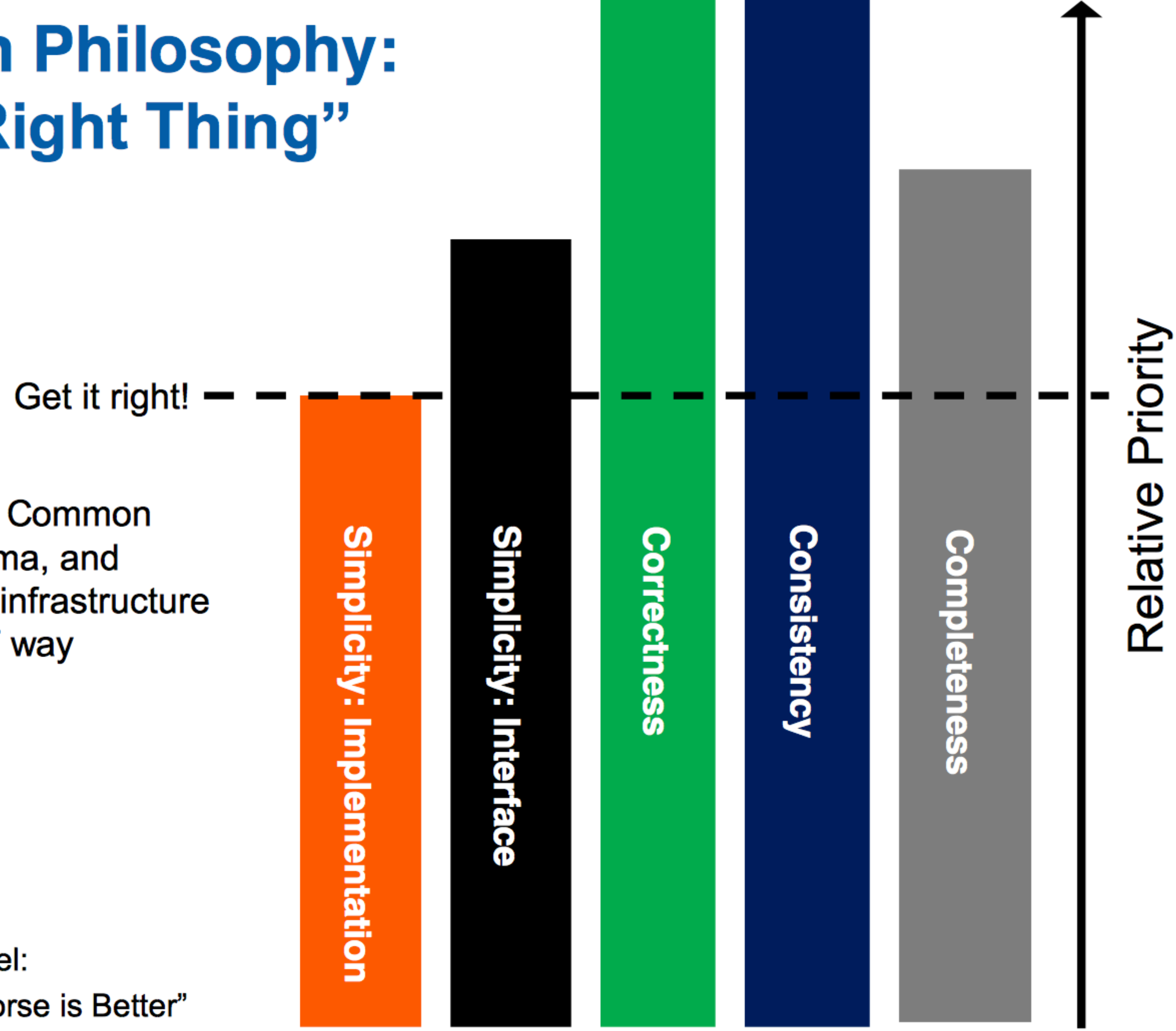

Example: Common Lisp, Schema, and supporting infrastructure … The MIT way

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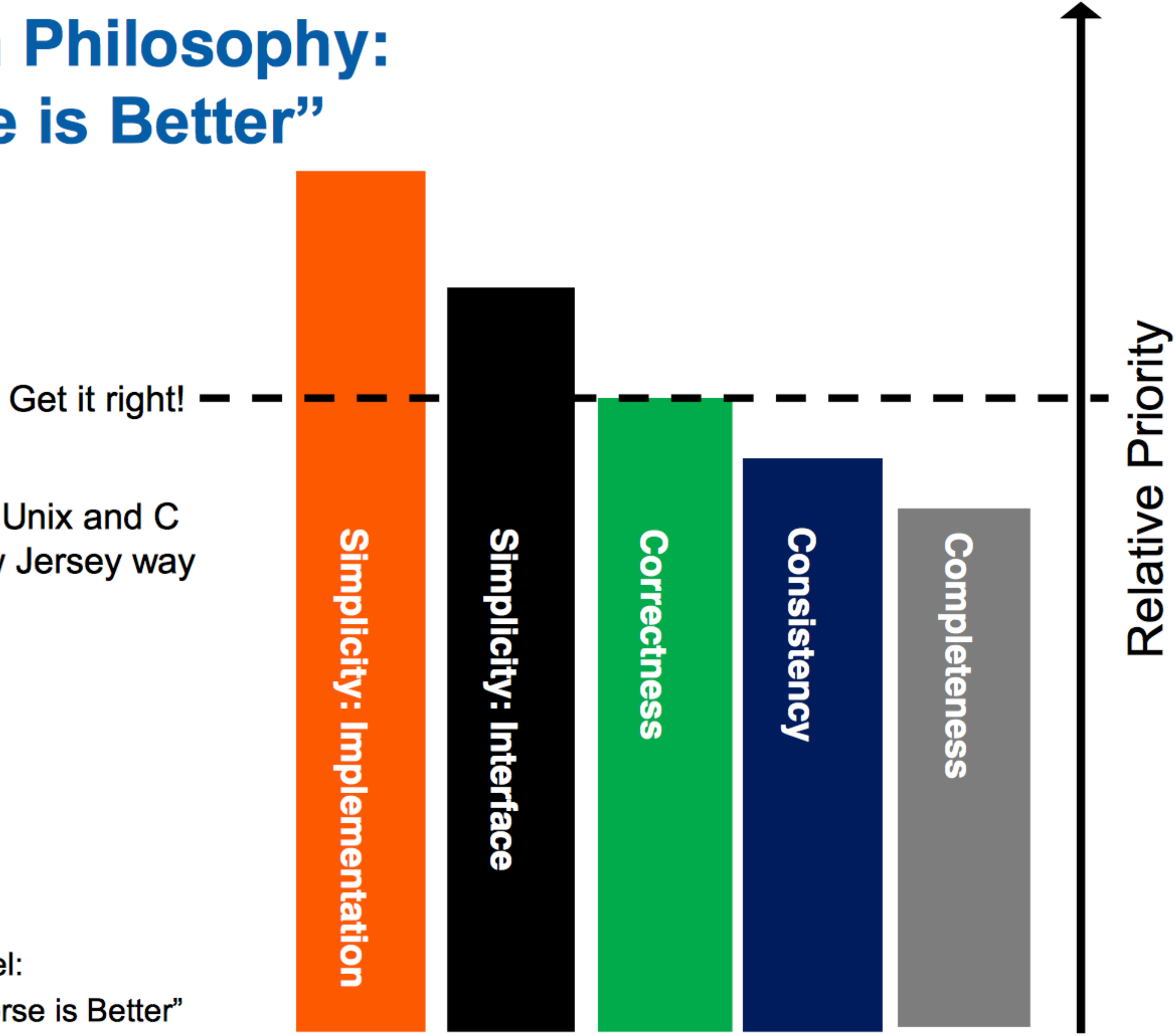
Design Philosophy: “Worse is Better”



Example: Unix and C
… The New Jersey way

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1.6 Compilers and Virtual Machines

Compiler – produces machine code

Interpreter – executes instructions on a virtual machine

- Example compiled languages:
  - *Fortran, Cobol, C, C++*
- Example interpreted languages:
  - *Scheme, Haskell, Python*
- Hybrid compilation/interpretation
  - *The Java Virtual Machine (JVM)*

The Compiling Process

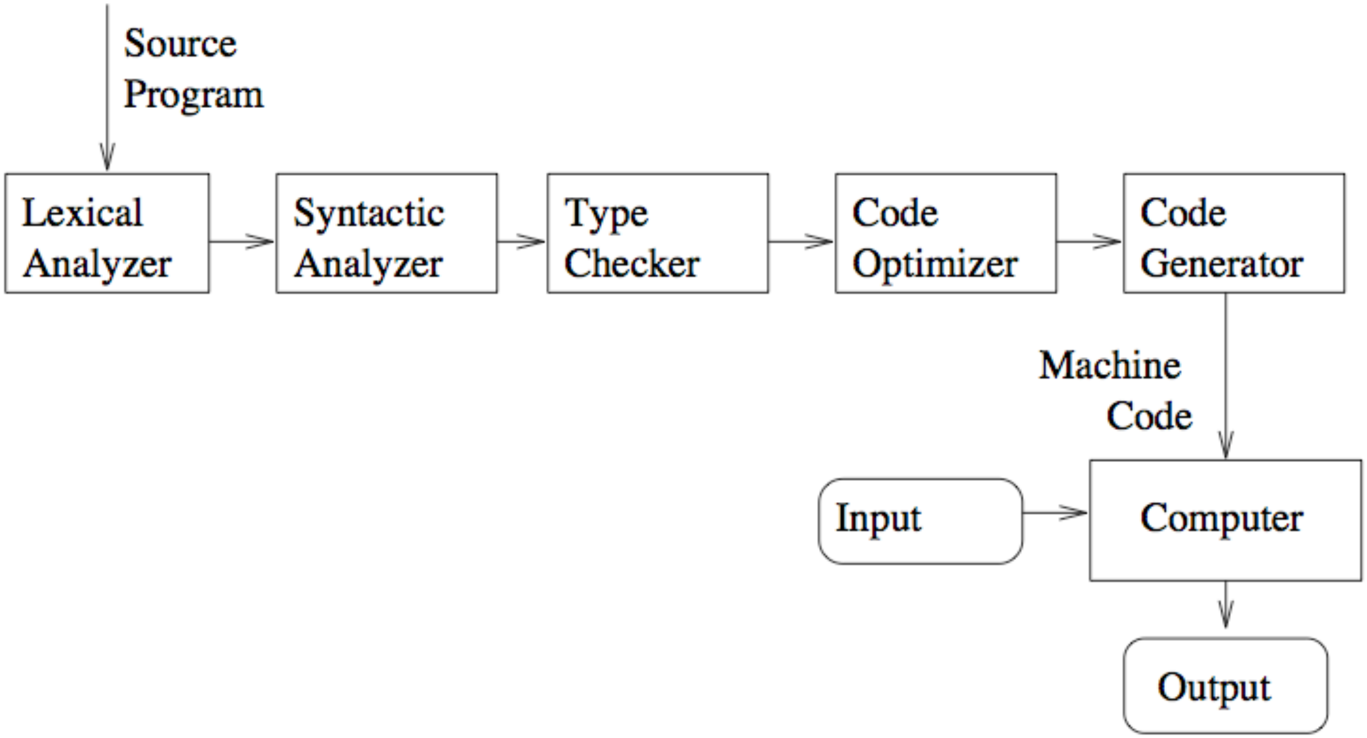

Figure 1.4: The Compile-and-Run Process

The Interpreting Process

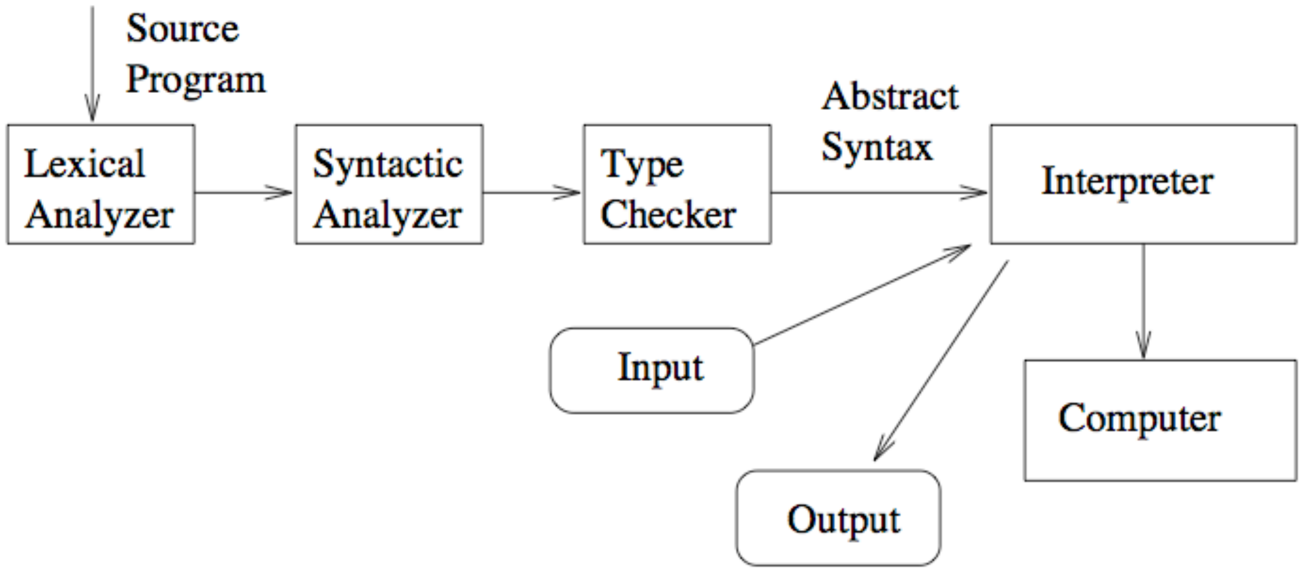

Figure 1.5: Virtual Machines and Interpreters