CS:3820
Programming Language Concepts

Fall 2016

Introduction and Overview

1 Principles

Distinguishing programming languages properties:

- Syntax
- Names
- Types
- Abstractions
- 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 ask questions like:

- What is the grammar for the language?
- What is the basic vocabulary?
- How are syntax errors detected?

Names

Various kinds of 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 of operations on those values

- Simple types
  - numbers, characters, Booleans, …
- Structured types
  - Strings, lists, trees, hash tables, …
- A language's *type system* can help:
  - determine legal operations
  - detect type errors
  - optimize certain operations

Abstractions

Mechanisms for generalizing computations or data:

- Procedures/functions
- Modules
- Abstract data types
- Classes
- Memory models

Semantics

The meaning of a program is called its *semantics*

In studying semantics, we ask questions like:

- When a program is running, what happens to the values of the variables?
- What does each construct do?
- What underlying model governs run-time behavior, such as function call?
- How are variables and objects allocated to memory at run-time?

2 Paradigms

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

There are several main programming paradigms:

$$\left.\begin{array}{l}\text{– Imperative}\\ \text{– Object-oriented}\\ \text{– Functional}\end{array}\right\}\text{ focus of this course}$$

- Logic
- Dataflow

Imperative Paradigm

Follows the classic von Neumann-Eckert model:

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

Example imperative languages:

- Cobol, Fortran, C, Ada, Perl, …

Object-oriented (OO) Paradigm

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

Major features:

- Encapsulated State
- Message passing
- Inheritance
- Subtype Polymorphism

Example OO languages:

Smalltalk, Java, C++, C#, Python, …

Functional Paradigm

Functional programming models a computation as a collection of mathematical functions

- Input = domain
- Output = range

Major features

- Functional composition
- Recursion
- Referential transparency

Example functional languages:

- Lisp, Scheme, ML, Haskell, F#,…

Functional Paradigm

Functional programming models a computation as a collection of mathematical functions

- Input = domain
- Output = range

Notable features of modern functional languages:

- Functions as values
- Symbolic data types
- Pattern matching
- Sophisticated type systems and module systems

Logic Paradigm

Logic programming declares what outcome of the program should be, rather than how it should be achieved

Major features:

- Programs as sets of constraints on a problem
- Computation of all possible solutions
- Nondeterministic computation

Example logic programming languages:

- Prolog, Datalog

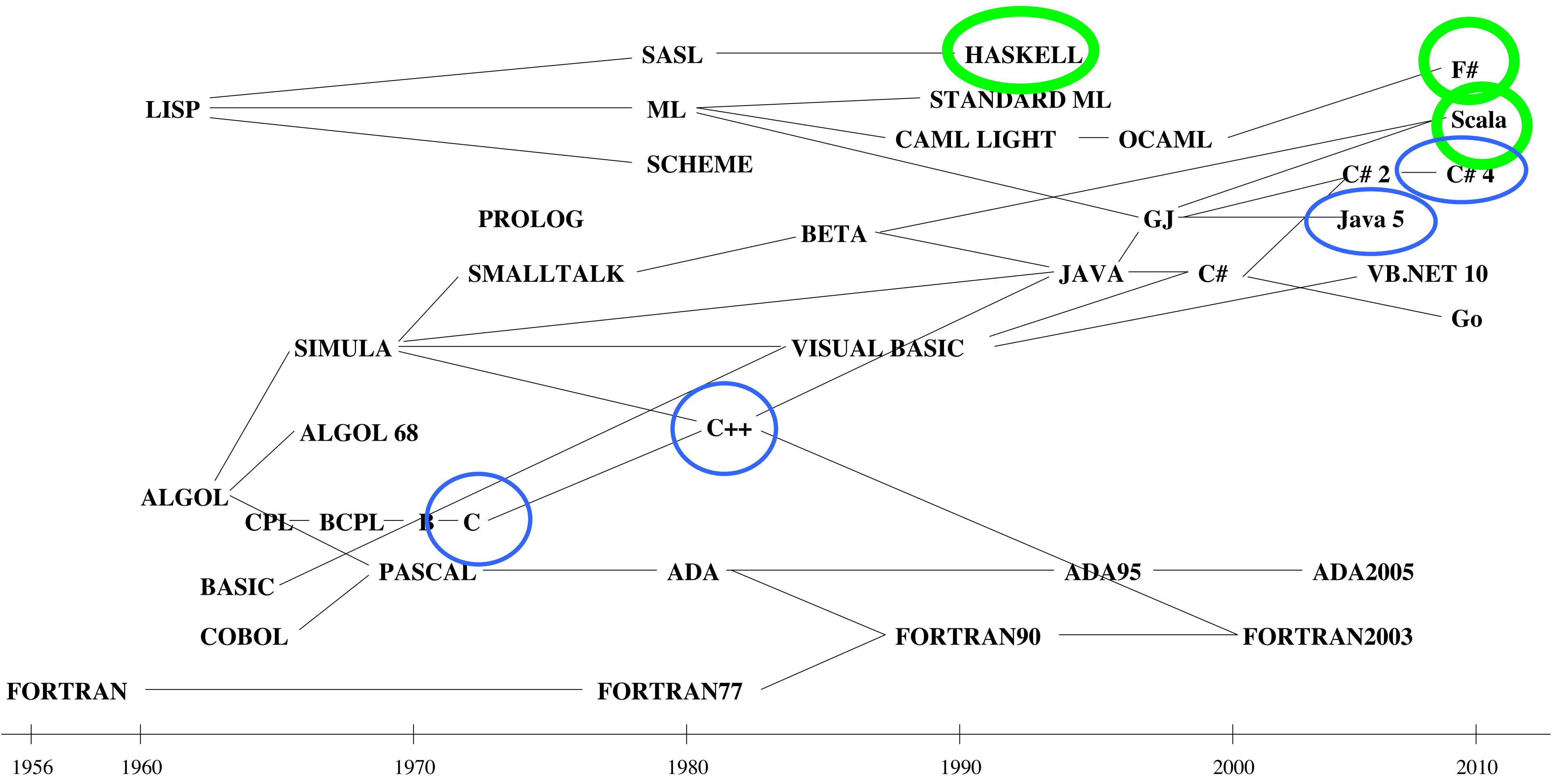
3 A Brief History

How and when did programming languages evolve?

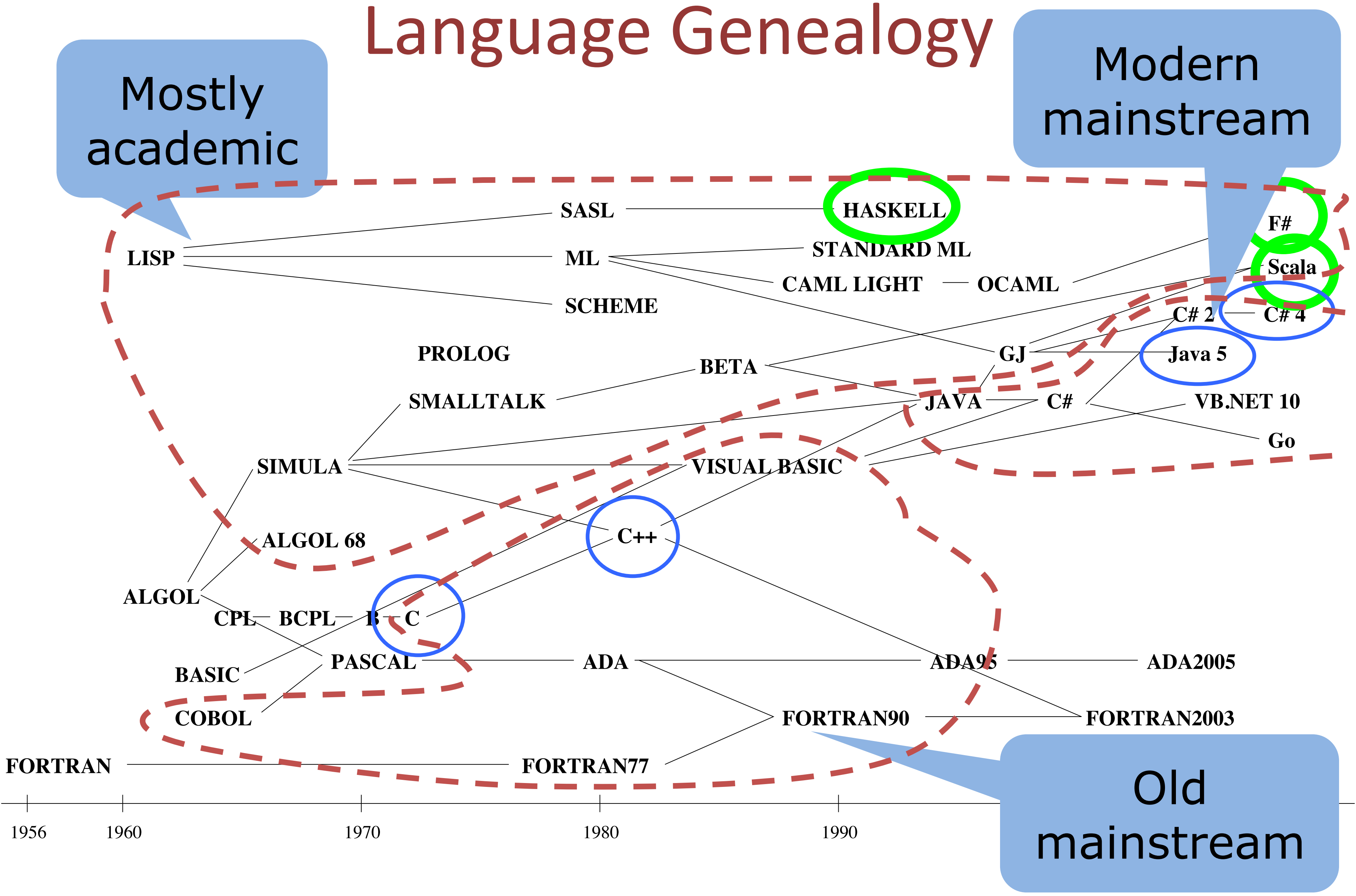
What communities have developed and used them?

- Artificial Intelligence
- Computer Science Education
- Science and Engineering
- Information Systems
- Systems and Networks
- World Wide Web
- …

Language Genealogy



Language Genealogy



4 On Language Design

Design Constraints

- Computer architecture
- Technical setting
- Standards
- Legacy systems

Design Outcomes and Goals

What makes a successful language?

Key characteristics:

- Simplicity and readability
- Reliability
- Support
- Abstraction
- Orthogonality
- Libraries
- Efficient implementation
- Community

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

Reliability

- Program behavior is the same on different platforms
  - E.g., early Fortran, C
- 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)

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

Efficiency Issues

- 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

5 Compilers and Interpreters

Compiler – produces machine code

Interpreter – executes instructions on a virtual machine

- Some compiled languages:
  - Fortran, C, C++, Rust, Swift
- Some interpreted languages:
  - Scheme, Python, Javascript
- Hybrid compilation/interpretation
  - Java Virtual Machine (JVM) languages (Java, Scala, Clojure)
  - .NET languages (C#, F#)

Compilation

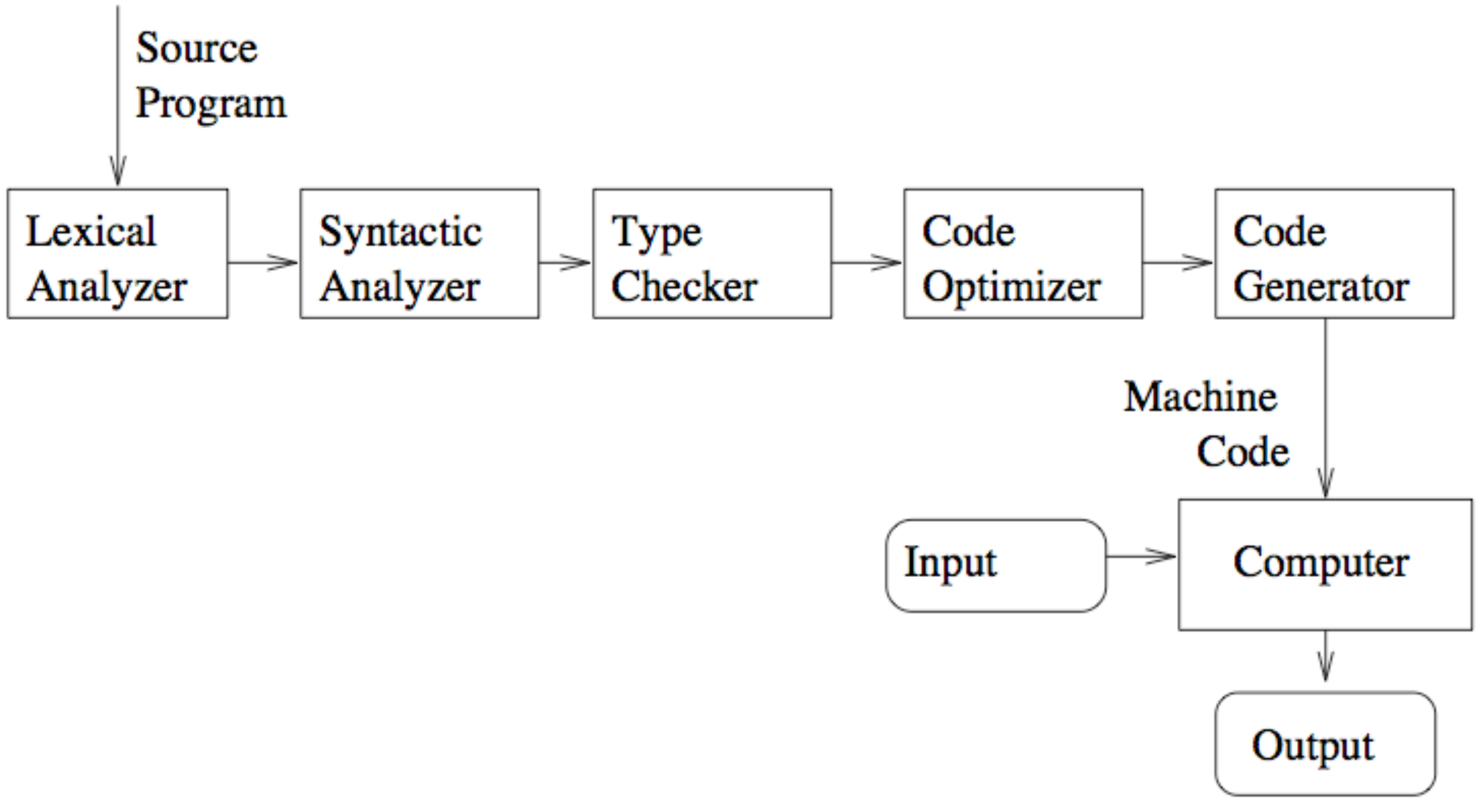


Figure 1.4: The Compile-and-Run Process

Interpretation

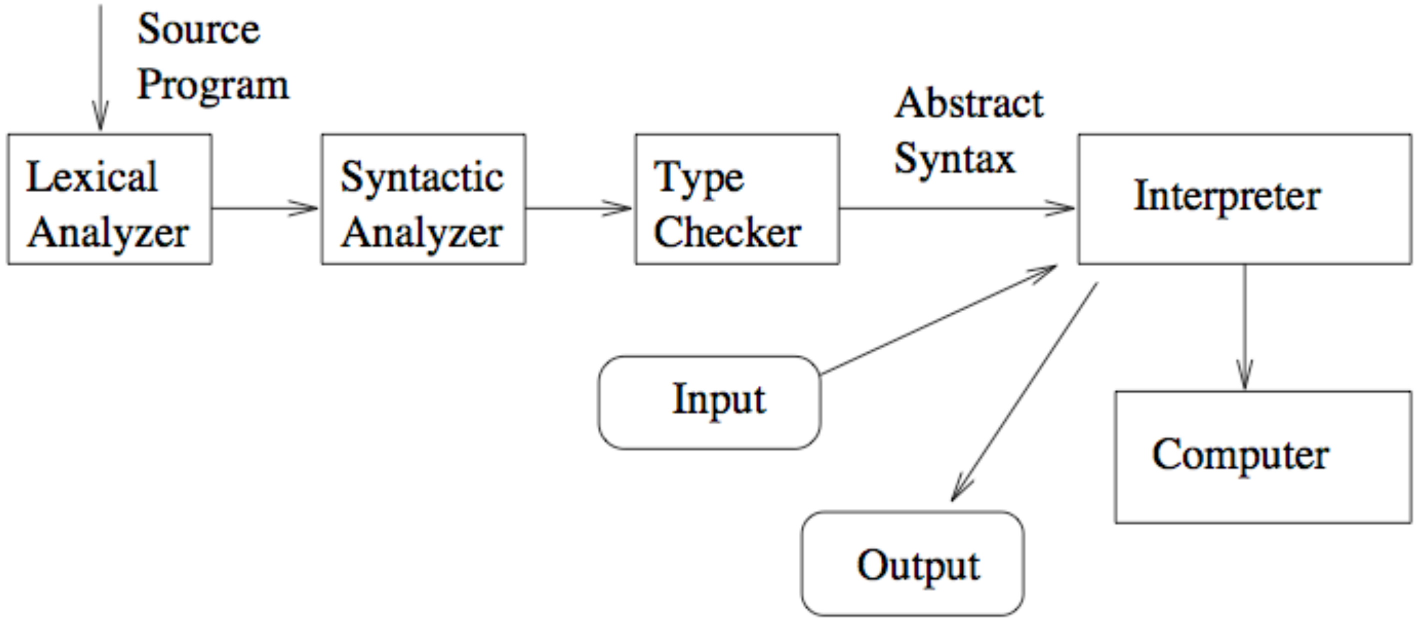


Figure 1.5: Virtual Machines and Interpreters

6 Course Contents

- A brief intro to functional programming with F#
- Lexical analysis, regular expressions, finite automata, lexer generators
- Syntax analysis, top-down versus bottom-up parsing, LL versus LR, parser generators
- Expression evaluation, stack machines, Postscript
- Compilation of a subset of C with *p, &x, pointer arithmetic, arrays
- Type checking, type inference, statically and dynamically typed languages
- The machine model of Java, C#, F#: stack, heap, garbage collection
- The intermediate bytecode languages of the Java Virtual Machine and .NET
- Garbage collection techniques, dynamic memory management
- Continuations, exceptions, a language with backtracking
- Selected advanced topics