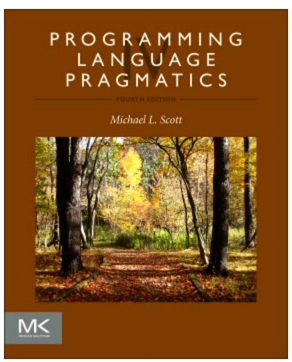
Introduction

17-363/17-663: Programming Language Pragmatics



Next edition: Scott & Aldrich!

Prof. Jonathan Aldrich

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Introduction

- Language Design and Language Implementation go together
  - An implementor has to understand the language
  - A language designer has to understand implementation issues
  - A good programmer has to understand both!

Introduction

- Why are there so many programming languages?
  - evolution -- we've learned better ways of doing things over time
  - socio-economic factors: proprietary interests, commercial advantage
  - orientation toward special purposes
  - orientation toward special hardware
  - diverse ideas about what works well (and what people like)

Introduction

- What is your favorite language, and why do you like it?

Introduction

- What makes a language successful?
  - easy to learn (BASIC, Python, LOGO, Scheme)
  - expressive, powerful (C++, Common Lisp, Scala, Rust)
  - easy to implement (BASIC, Forth)
  - possible to compile to very good (fast/small) code (Fortran, C)
  - backing of a powerful sponsor (C#, Ada, Swift)
  - wide dissemination at minimal cost (Pascal, Java)
  - market lock-in (Javascript)

Introduction

- Why do we have programming languages? What is a language for?
  - way of thinking / way of expressing algorithms
    - languages from the user's point of view
  - abstraction of virtual machine -- way of specifying what you want the hardware to do without getting down into the bits
    - languages from the implementor's point of view

Why study programming languages?

- Help you choose a language.
  - C++ vs. Rust for systems programming
  - Fortran vs. Julia for numerical computations
  - Python vs. JavaScript for web applications
  - Ada vs. C for embedded systems
  - Common Lisp vs. Scheme vs. ML for symbolic data manipulation
  - Java vs. Scala for application servers

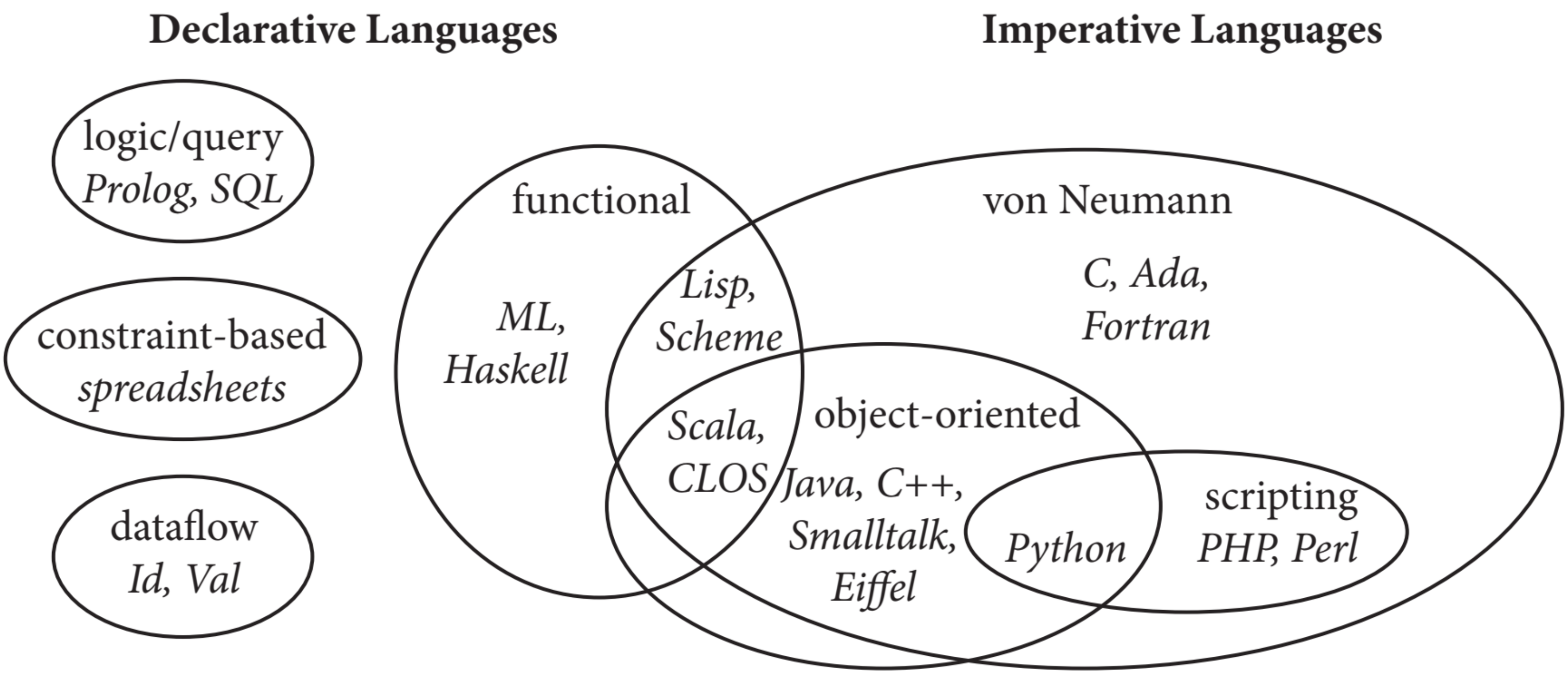
Why study programming languages?

- Make it easier to learn new languages
  - Familiarity with related languages
  - Understanding core concepts that reappear
- Use language/compiler ideas in your projects
  - Almost every complex system has a language somewhere!
- Learn how to reason rigorously
  - PL has some of the best intellectual tools!

Why study programming languages?

- Help you make better use of whatever language you use
  - Specialized features
    - unions, first-class functions, …
  - Implementation costs
    - Garbage collection, tail recursion
  - Emulating missing features
    - Recursion (with loops and stacks)
    - First-class functions (with objects)…or vice versa!

Language Paradigms



How is this course different?

- Overall: emphasizes the interaction between language design and implementation
- Vs. 15-410
  - More focus on language design and theory; fulfills the Logic & Languages elective, not the Systems elective
- Vs. 15-312
  - "Pragmatic" focus – we study ideas and theory in the context of industrial languages and their design choices
  - Use of an educational proof assistant to make theory both more approachable and rigorous

Course Staff

Prof. Jonathan Aldrich

TA Bradley Teo

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Course Administration

- Lectures 2x/week
  - Active learning exercises in every class
  - In person expectation
    - If you can't make it (COVID is not gone, but there may be other reasons too), email me—I'll get you a video & exercises
- Textbook: Programming Language Pragmatics
  - Strongly recommended: supplements lecture with more depth
  - Please give me feedback—I'm coauthoring the next edition!
- Recitation
  - Lab-like, helpful for homework. Bring your laptop!

“How do I get an A?”

- 50% Homework –due Tues/Thurs 11:59pm
  - Small warm-up assignment due this Thursday
  - Build a compiler (4 coding assignments)
    - Implementation in Ocaml – great language & libraries for writing compilers
  - Reason about languages (4 theory assignments)
    - SASyLF educational theorem proving tool
- 20% - 2 midterm exams covering core concepts
- 25% Project
  - Extend the compiler in some interesting way, or explore theory
- 5% Participation (assessed via in-class exercises)
  - Can miss up to 2 sessions (lecture or recitation) w/o losing credit

Communication

- Website
  - Schedule, syllabus, slides
- Piazza for announcements, communication
  - Use Piazza as much as possible
  - Make questions public if possible, so others can benefit!
- Canvas
  - Assignments, grades
- Office hours (or just come by)
  - This week: Thursday 6pm
    - Come if you have challenges with installation or getting started on HW0
  - Will be a vote for times on Piazza

Read the Syllabus

A high level summary of some policies:

- Late work: 5 free late days
  - 10% penalty per day after these are used up
  - No credit more then 5 days late
  - Special circumstances: contact the instructor
- Collaboration policy
  - Your work must be your own
  - 100% penalty for cheating
  - Read full policy carefully
- No electronics in lecture
  - But bring them to recitation!

CMU can be pretty intense

- A 12-credit course is expected to take ~12 hours a week.
- We aim to provide a rigorous but tractable course.
  - More frequent assignments rather than big monoliths
  - Two midterm exams to cover core material as you learn it
- Please keep us apprised of how much time the class is actually taking and whether it is interfacing badly with other courses.
  - We have no way of knowing if you have three midterms in one week.
  - Sometimes, we misjudge assignment difficulty.
- If it’s 2 am and you’re panicking…put the homework down, send us an email, and go to bed.

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Executing programs

- Consider the following program
  - In a simple imperative language, Hoare's WHILE

```
y := x;
z := 1;
while y > 1 do
  z := z * y;
  y := y - 1
```

- How do we run this sequence of characters?

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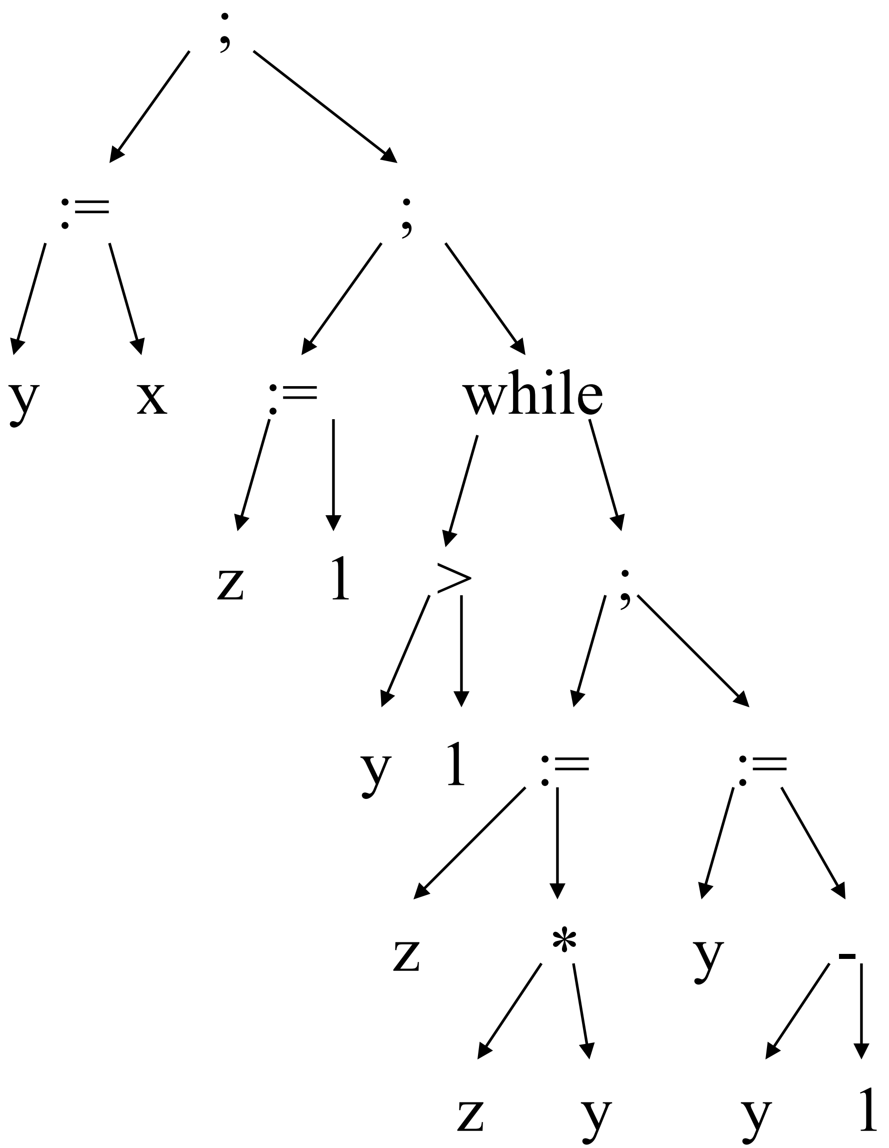
Programs as trees

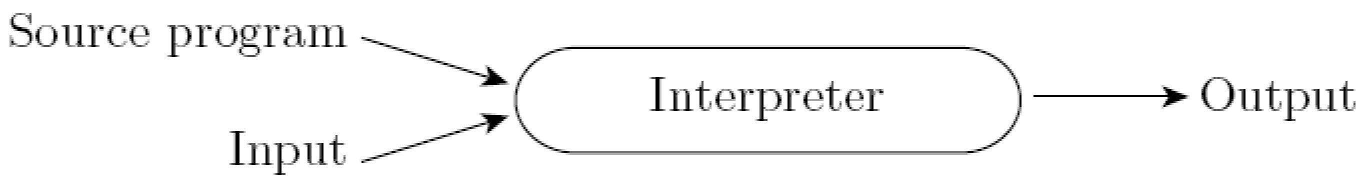
- What if we organize it as a tree in memory

```
y := x;
z := 1;
while y > 1 do
  z := z * y;
  y := y - 1
```



- Now we can walk the tree and execute it

Interpreters



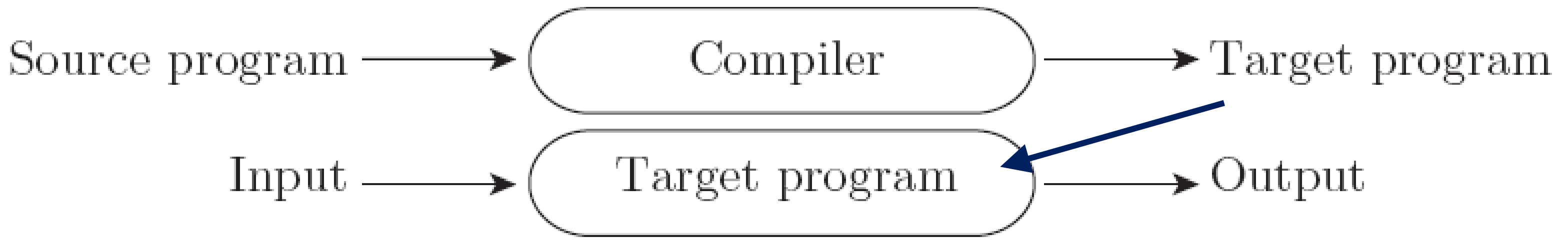
- Interpreter runs at execution time
  - Operates over the program as a data structure
- A simple and flexible approach—but slow
  - We examine the program to determine what to do, over and over again

A Pattern for Simple Interpreters

function interpret_expr(a : AST) : **int**
    case a **of**
        int_lit(n) : **return** n
        bin_op(a_1, op, a_2) :
            let v_1 : **int** = interpret_expr(a_1)
            let v_2 : **int** = interpret_expr(a_2)
            case op **of**
                "+" : **return** $v_1 + v_2$
                "–' : **return** $v_1 - v_2$
                "×" : **return** $v_1 * v_2$
                "÷" : **return** v_1 / v_2

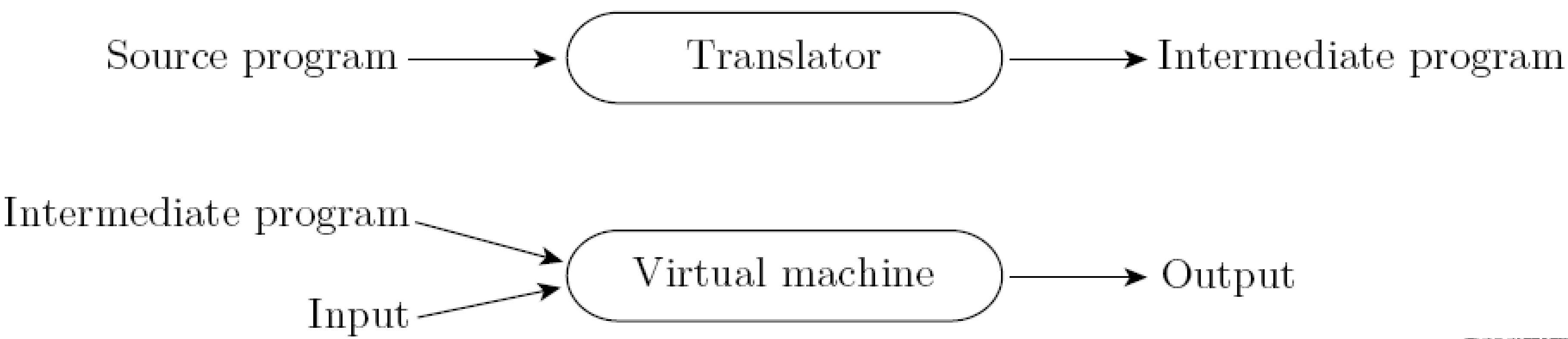
Compilers

- A compiler translates the high-level source program into an equivalent target program (typically in machine language), and then goes away:



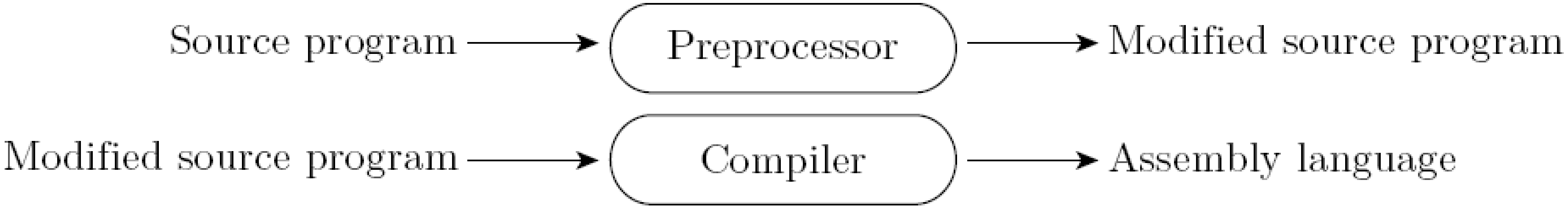
Virtual Machine Targets

- A common case is compilation to a virtual machine target
  - E.g. Java source to JVM bytecode
  - The virtual machine can itself be an interpreter or a compiler
- Why is this useful?



Compilation: Preprocessing

- The C Preprocessor (conditional compilation)
  - Preprocessor deletes portions of code, which allows several versions of a program to be built from the same source

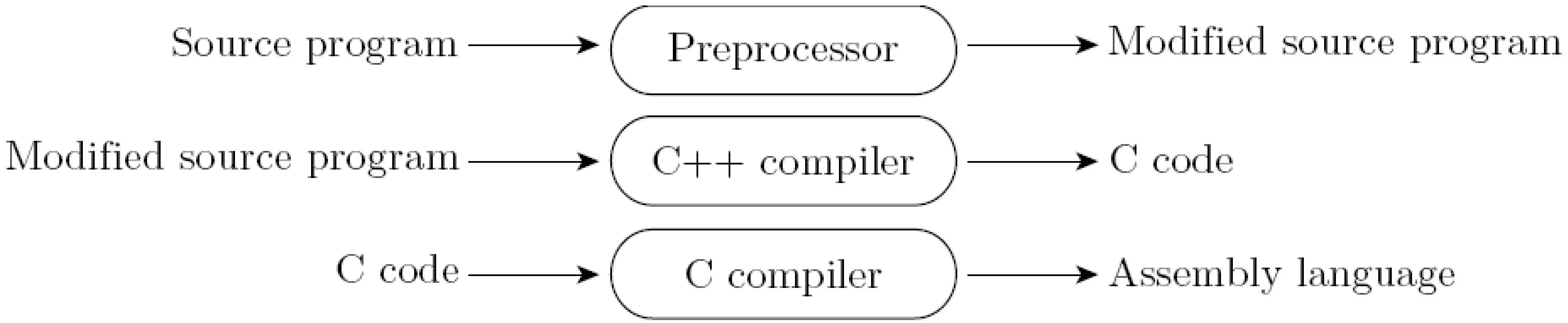


Compilation vs. Preprocessing

- Note that compilation does NOT have to produce machine language for some sort of hardware
- Compilation is *translation* from one language into another, with full analysis of the meaning of the input
- Compilation entails semantic *understanding* of what is being processed; pre-processing does not
- A pre-processor will often let errors through. A compiler hides further steps; a pre-processor does not

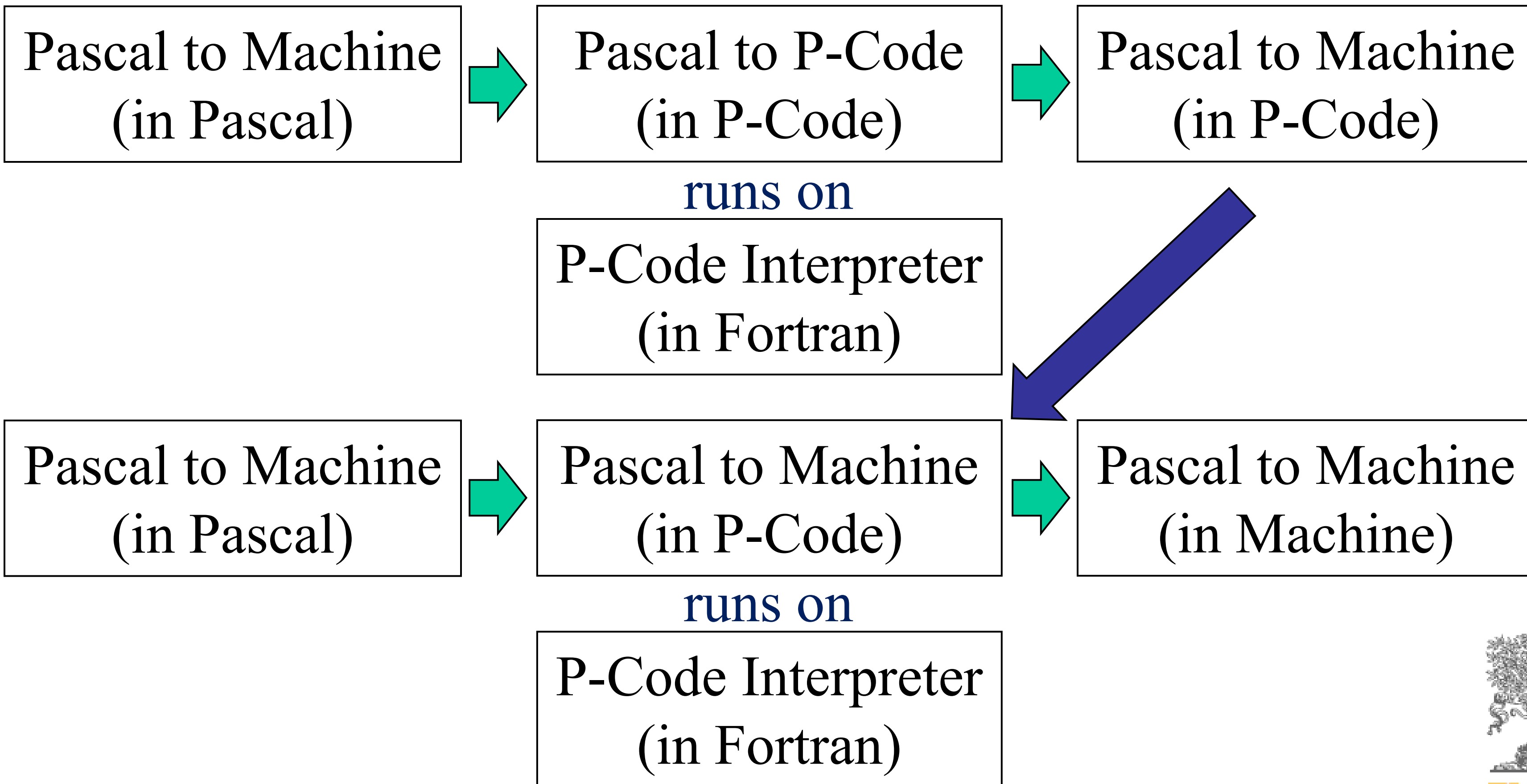
Compilation Strategies

- Source-to-Source Translation (C++)
  - C++ implementations based on the early AT&T compiler generated an intermediate program in C, instead of an assembly language:



Compilation Strategies

- Bootstrapping

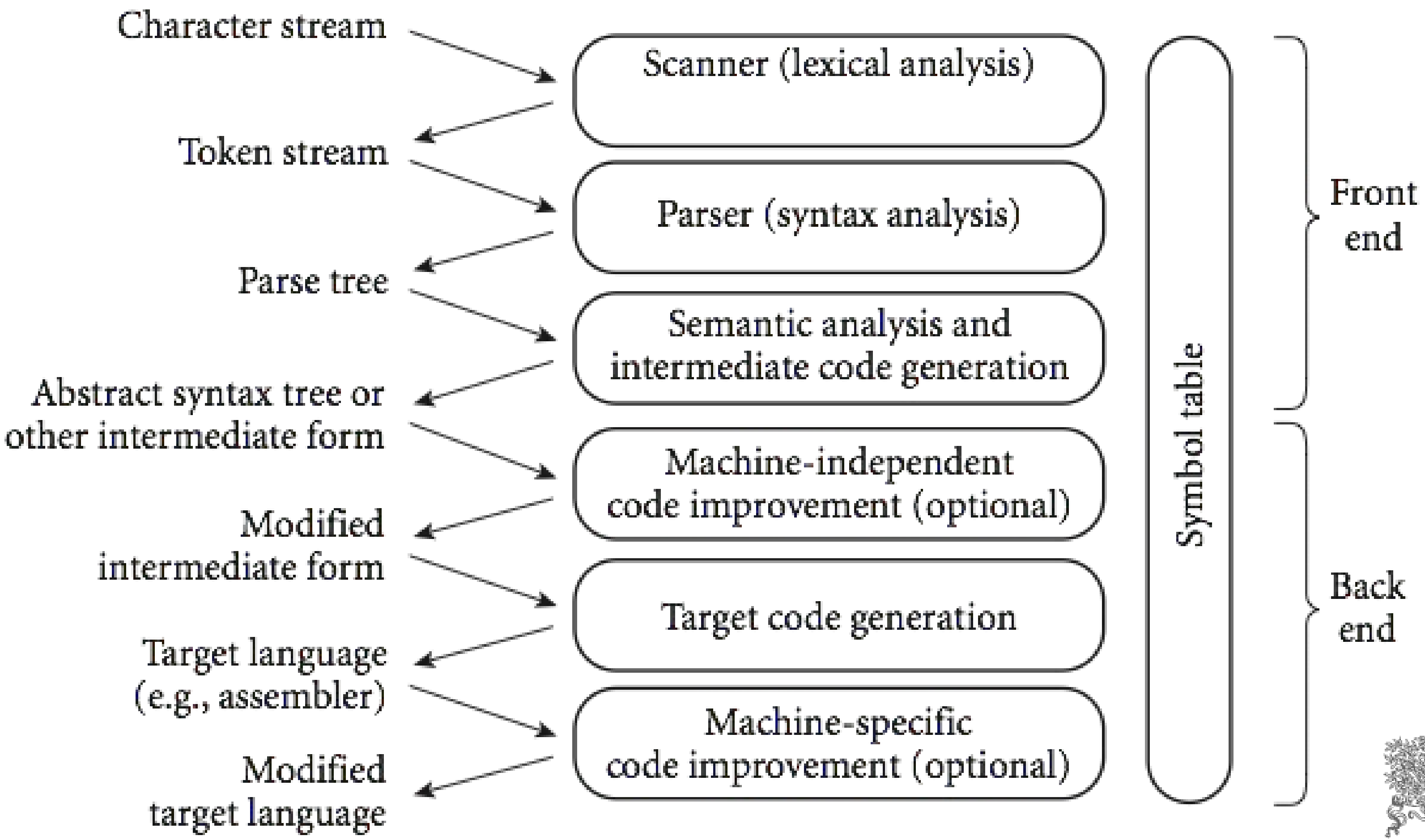


Compilation vs. Interpretation

- Compilation produces the fastest programs
- So why interpret?
  - Allows delaying decisions to run time
    - Names to objects, types of objects, even what code is run
      - Used in dynamic/scripting languages (Scheme, Python, Shell scripts, …)
    - Compilation can account for these, but becomes complex and somewhat slower anyway
  - Small code size
  - Good diagnostics—interpreter state is available
  - Fast startup (don't have to wait for the compiler)
  - Easy to write and port

An Overview of Compilation

- Phases of Compilation



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Scanning / Lexical Analysis

- Input program:

```
y := x;
z := 1;
while y > 1 do
  z := z * y;
  y := y – 1
od
```

- Output of scanner is a stream of *tokens*:

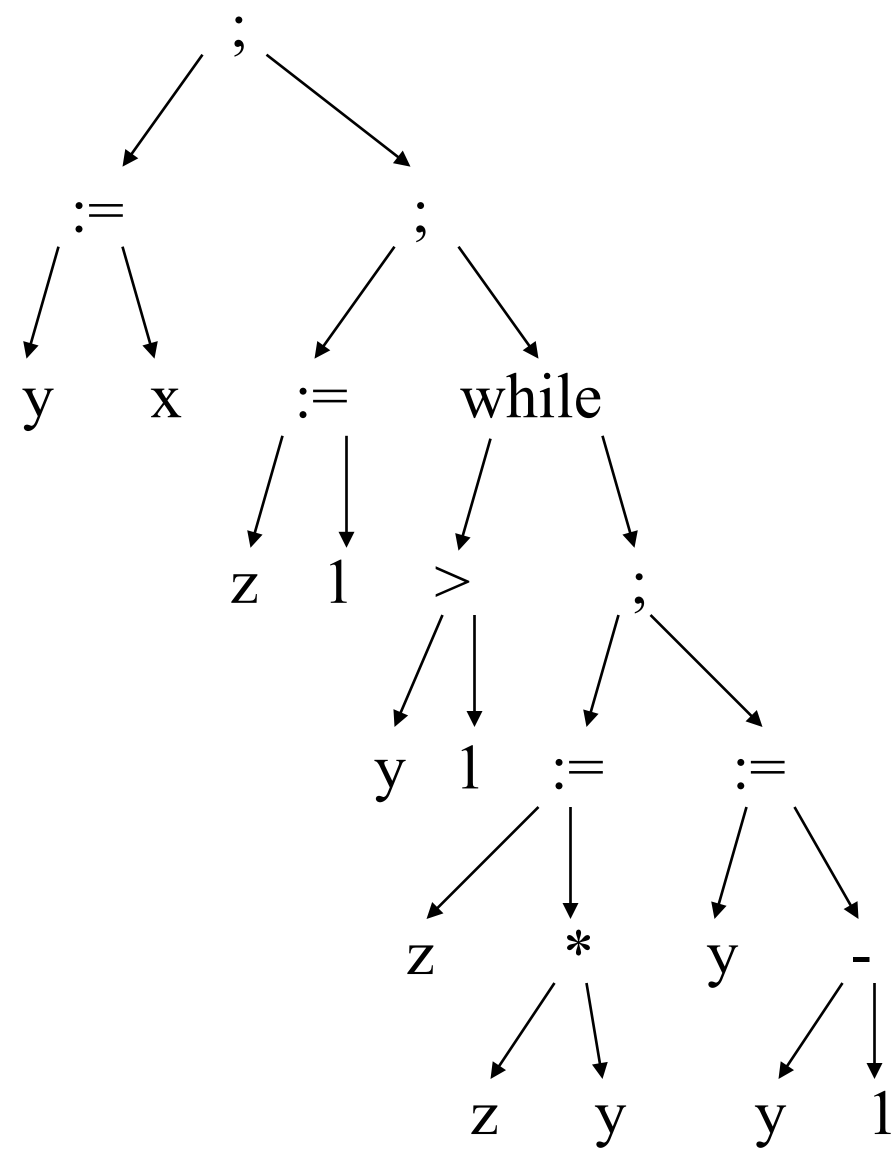
```
y := x ; z := 1 ; while y > 1 do z := z * y ; y
:= y – 1 od
```

Scanning / Lexical Analysis

- divides the program into "tokens", which are the smallest meaningful units; this saves time, since character-by-character processing is slow
  - scanning is recognition of a *regular language*, e.g., via a DFA
- removes comments
- saves text of identifiers, strings, numbers
- tags tokens with line numbers, for error messages
- main benefits: efficiency, simplifies later stages
  - you can design a parser to take characters instead of tokens as input, but it isn't pretty

Parsing

```
y := x;
z := 1;
while y>1 do
        z := z * y;
        y := y – 1
```



Semantic analysis

- ***Semantic analysis*** is the discovery of *meaning* in the program
  - The compiler actually does what is called STATIC semantic analysis. That's the meaning that can be figured out at compile time
    - E.g. typechecking, which catches errors and helps generate code (e.g. floating point vs. integer add)
  - Some things (e.g., array subscript out of bounds) usually can't be figured out until run time. Things like that are part of the program's DYNAMIC semantics

Concrete vs. Abstract Syntax Trees

- *Concrete* syntax trees capture exactly the syntax in the source program

- *Abstract* syntax trees (ASTs) simplify things
  - E.g. getting rid of parentheses, which are only necessary to show the intended tree structure

An Overview of Compilation

- ***Intermediate form*** (IF) done after semantic analysis (*if* the program passes all checks)
  - IFs are often chosen for machine independence, ease of optimization, or compactness (these are somewhat contradictory)
  - They often resemble machine code for some imaginary idealized machine; e.g. a stack machine, or a machine with arbitrarily many registers
  - Many compilers actually move the code through more than one IF

An Overview of Compilation

- ***Optimization*** takes an intermediate-code program and produces another one that does the same thing faster, or in less space
  - The term is a misnomer; we just *improve* code (but see superoptimization)
  - Can be very complex and take a long time—but also produce significant speedup
  - The optimization phase is optional

An Overview of Compilation

- ***Code generation*** produces assembly language or (sometime) relocatable machine language
  - Allocating registers to store data
  - Machine-specific optimizations

Programming Language Pragmatics

- PL is an exciting field to study
  - Interesting theory
  - Important impact on practice
  - Lots of applications
  - Will help you become a better programmer

- For next time:
  - Get the textbook and read through chapter 2.2
  - Homework “zero” is out today, due Thursday
  - The first real homework will be out Thursday