Programming Languages

Lecture 2: Translators & Virtual Machines

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Lecture Outline

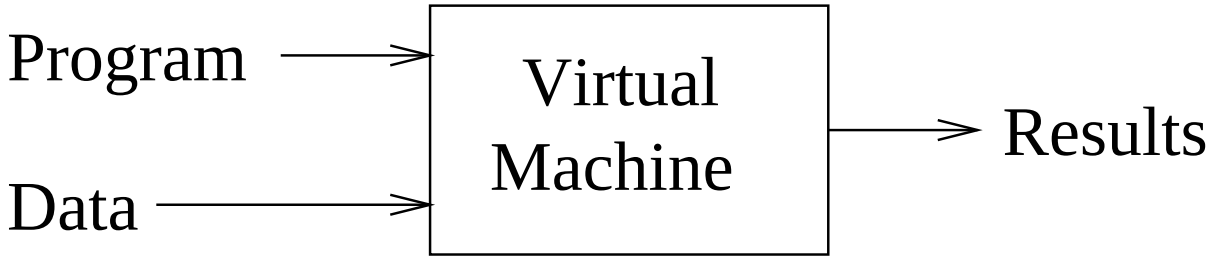
- Abstraction
- Translators
- Compilers
- Interpreters
- Semantics

Languages as Abstraction

- Programming language creates a virtual machine for programmer
- Dijkstra: Originally we were obligated to write programs so that a computer could execute them. Now we write the programs and the computer has the obligation to understand and execute them.
- Progress in programming languages characterized by increasing support of abstraction

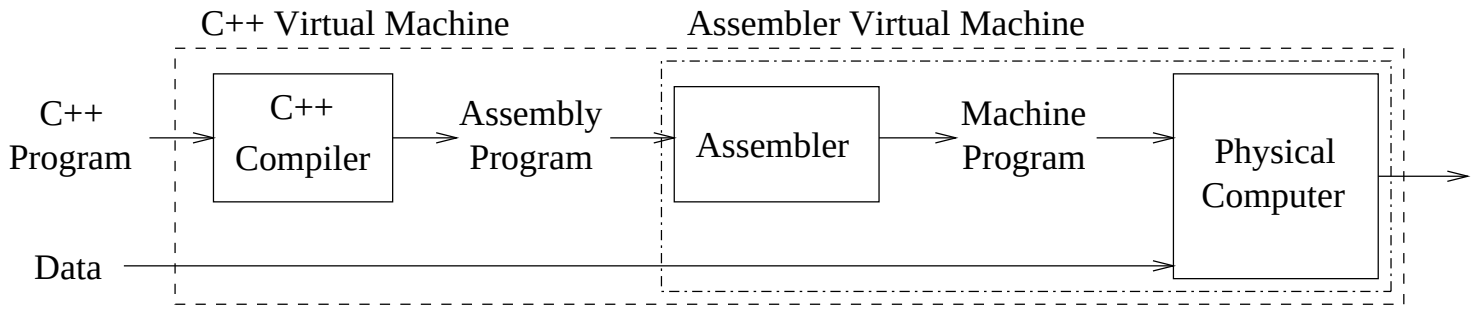
Virtual Machines

- Machine language provides "raw" machine to execute programs
- Even machine language abstracts away from physical nature of computation
- Higher level language presents programmer with a more abstract model of a computer
- Language creates the illusion of a more sophisticated virtual machine



Virtual Machines (cont)

- Virtual machines built-up using translators and other virtual machines



- (Virtual) Machine language is instruction set supported by translator
- Virtual machine determined by implementation

Problems

- Possibilities
  - Different implementors have different conceptions of virtual machine
  - Different computers
  - Implementors may choose different ways to simulate virtual machine
- Combined can lead to different implementations (on same machine)
- How can we ensure that all implementations have same semantics?

Explicit Virtual Machines

- Pascal P-code and P-machine
- Modula-2 M-code and M-machine
- Java Bytecode and Java virtual machine
- Prolog and Warren Abstract Machine

Translators

- Some high-level languages have special purpose processors (LISP machine)
- Most high-level languages must be translated
- Two types of translators
  - interpreter
  - compiler
- Usually combination of the two

Pure Interpreter

- Simulate virtual machine

```
Repeat
  Get next statement
  Determine action(s)
  Call routines to perform action(s)
Until done
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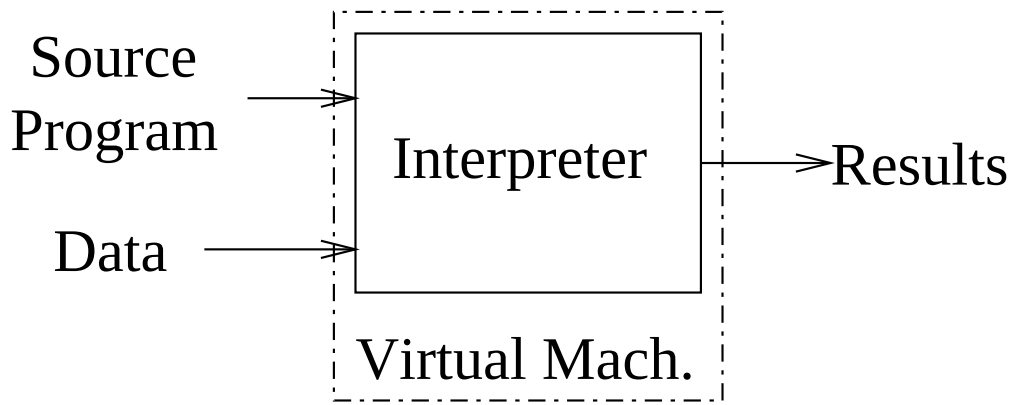
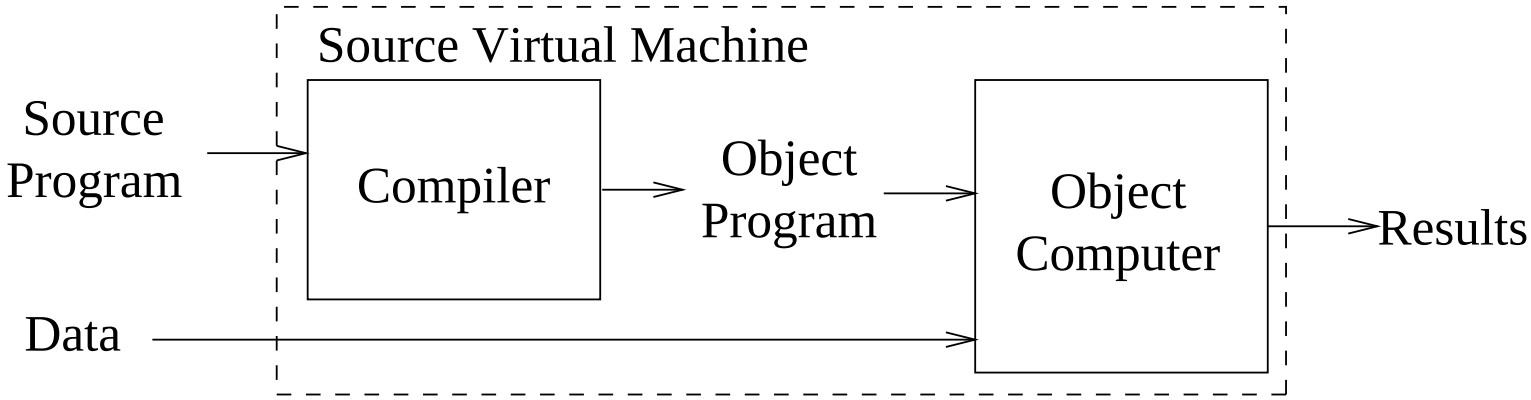


Pure Compiler

- Executing program
  1. Translates all units of program into object code (e.g., machine language)
  2. Link into single relocatable machine code
  3. Load into Memory



Compilation vs Interpretation

Compiler	*Interpreter*
Each statement translated once	Translate only if executed
Must compile	Run immediately
Faster execution	Allows more supportive environment
Only object code in memory when executing	Interpreter in memory
Object file likely large	Source likely smaller

Mixed Translation

- Rare to have pure compiler or pure interpreter
- Typically compile into easier to interpret form
- Example: abstract syntax tree (compact representation of parse tree)
- Usually go farther into intermediate code (Java Bytecode) and then interpret

Compilation

- Two primary phases
  1. Analysis: tokenize, parse, generate simple intermediate code (type checking)
  2. Synthesis: optimization (instructions in context), code generation, linking and loading
- To build portable compiler, separate into front- and back-end
  - Front-end does analysis and some optimization of intermediate code
  - Back-end does code generation and full optimization

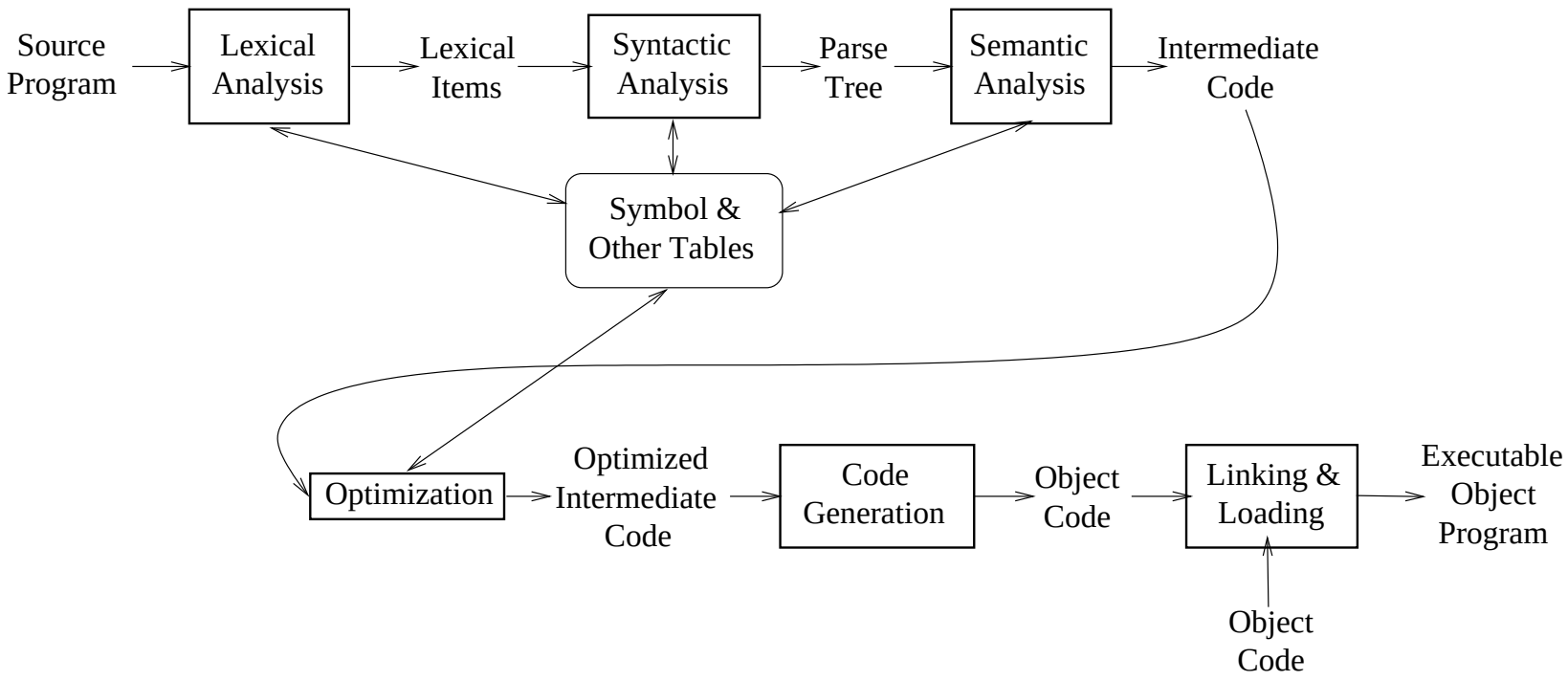
Analysis Phase

1. Lexical analysis — break program into lexemes (identifiers, operation symbols, keywords, punctuation, comments, etc.) Convert lexeme into token consisting of lexeme and token type.
2. Syntactical analysis — Use formal grammar to parse program and build parse tree (maybe implicitly). Add identifiers to symbol table.
3. Semantic analysis — Update symbol table (e.g., add type info). Insert implicit information (resolve overloaded operations), error detection, type checking. Traverse parse tree generating intermediate code.

Synthesis Phase

1. Optimization — Find adjacent store-reload instructions, evaluate common sub-expressions, move static code out of loops, allocate registers, etc.
2. Code generation — Generate assembly or machine code (sometimes C)
3. Linking and Loading — Resolve external references between separately compiled units. Make sure that all references are relative to beginning of program. Load program into memory.

Compiler Structure



Symbol Table

- Contains
  1. identifier names
  2. kind of identifier (variable, array, procedure, formal parameter)
  3. type
  4. visibility
- Used to check for errors and code generation.
- May be thrown away at end of compilation
- Kept for error reporting or dynamic name generation

Semantics

- Meaning of program
  - Formal semantics (operational)
  - How would an interpreter for the language work on a virtual machine?
- Work with virtual/abstract machine when discussing semantics of programming language constructs.
  - Represent *data* and *code* portions of memory
  - Instruction pointer, *ip*, incremented after each instruction if not explicitly modified
- Run program by loading it into memory and initializing *ip* to beginning of program.

Official Language Definitions

- Standardize syntax and semantics to promote portability
- All compilers should accept the same programs
- All legal programs should give the same answers (modulo differences in arithmetic, etc.)
- Designed for compiler writers and as programmer reference

Official Definitions (cont)

- Often better to standardize after gaining implementation experience (Ada standard before implemented)
- Common Lisp, Scheme, ML now standardized, Fortran 90, C++
- Standards include good formal definitions of syntax, but semantics still too hard
- Backus promised formal semantics in Algol 60 report — still waiting!