

Overview of Compilers and Interpreters

- Common compiler and interpreter configurations
- Virtual machines
- Integrated programming environments
- Compiler phases
 - Lexical analysis
 - Syntax analysis
 - Semantic analysis
 - Code generation

Note: These slides cover Chapter 1 of the textbook

Compiling and Interpreting Programming Languages

- The *compiler*² versus *interpreter*² implementation is often fuzzy
 - One can view an interpreter as a *virtual machine*²
 - A *processor* (CPU) is an implementation in hardware of virtual machine for *machine code*
- Some languages cannot be purely compiled into machine code when the language allows a program to rewrite its own code, requiring the interpreter or virtual machine to invoke the compiler
- In general, compilers try to be as smart as possible to fix decisions that can be taken at compile time to avoid to generate code that makes a decision at run time
- Compilation leads to better performance in general
 - Allocation of variables without variable lookup at run time
 - Aggressive code optimization to exploit hardware features
- Interpretation leads to better diagnostics of a programming problem
 - Procedures can be invoked from command line by a user
 - Variable values can be inspected and modified by a user

Compilation and Interpretation

- *Compilation (conceptual):*

Source Program ® **Compiler** ® Target Program
Input ® **Target Program** ® Output

- *Interpretation (conceptual):*

Source Program ® **Interpreter** ® Output
Input ®

Pure Compilation and Linking

- Adopted by the typical Fortran implementation
- Library routines are separately linked **2** (merged) with the object code of the program

Source Program ® **Compiler** ® Incomplete Object Code
Incomplete Object Code ® **Linker** ® Object Code
Library Routines ®

Compilation, Assembly, and Linking

- Adopted by most compilers
- Facilitates debugging of the compiler

Source Program ® **Compiler** ® Assembly
Assembly ® **Assembler** ® Incomplete Object Code
Incomplete Object Code ® **Linker** ® Object Code
Library Routines ®

Mixed Compilation and Interpretation

- Adopted by Pascal, Java, functional and logic languages, and most scripting languages
- Pascal compilers generate *P-code* that can be interpreted or compiled into object code
- Java compilers generate *byte code* that is interpreted by the JVM virtual machine (or translated into machine code by a just-in-time (JIT) compiler)
- Functional and logic languages are compiled, but also allow dynamically created code to be compiled at run time for which the virtual machine invokes the compiler

Source Program ® **Translator** ® Intermediate Program
Intermediate Program ® **Virtual Machine** ® Output
Input ®

Preprocessing

- Compilers for C and C++ adopt a preprocessor²
Source Program ® **Preprocessor²** ® Modified Source Program
Modified Source Program ® **Compiler²** ® Assembly²
- Early C++ compilers generated intermediate C code
Source Program ® **Preprocessor²** ® Modified Source Program
Modified Source Program ® **C++ Compiler²** ® C Code
C Code ® **C Compiler²** ® Assembly²

Integrated Programming Environments

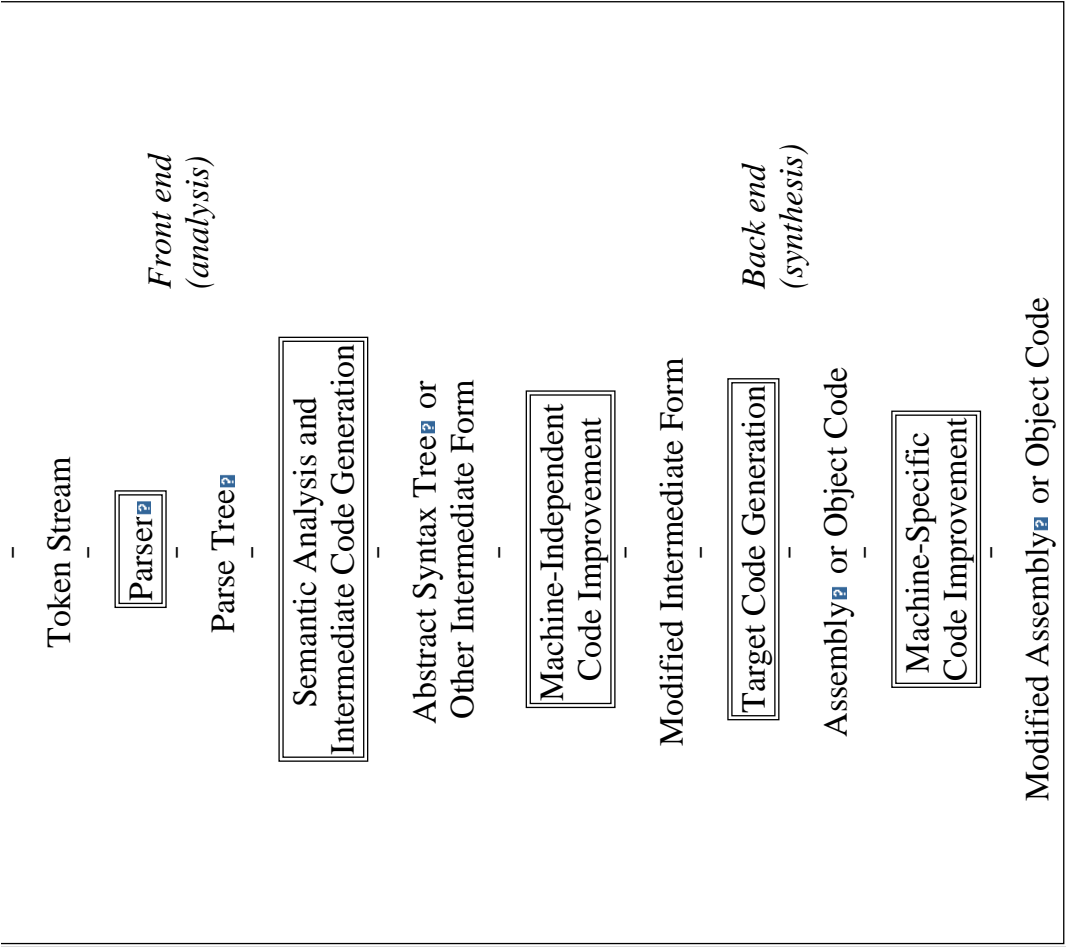
- Programming tools (editors, compilers, interpreters, debuggers) function together in concert
- Trace facilities to monitor execution of the program
- Upon run time error in compiled code the editor is invoked with cursor at source line
- Fundamental to Smalltalk-80
- Java Studio, Visual C++, VisualStudio

Overview of Compilation

- Compilation of a program proceeds through a series of *phases* where subsequent phases use information found in an earlier phase or uses a form of the program produced by an earlier phase
- Each phase may consist of a number of *passes* over the program representation

Character Stream

Scanner²



Lexical Analysis

- Lexical analysis breaks up a program (e.g. in Pascal)

```
program gcd (input, output);
var i, j : integer;
begin
  read (i, j);
  while i <> j do
    if i > j then i := i - j else j := j - i;
    writeln (i)
  end.
```

into a stream of *tokens*

```
program gcd ( input , output ) ;
var read ( i , j ) ;
i <> j do if i := i - j then j := j - i ;
:= j - i ; end .
```

- This is also known as *scanning* performed by a *scanner*

Note: a scanner in Java

Context-Free Grammars

- A *context-free grammar* defines the *syntax* of a programming language
- The grammar defines *syntactic categories*
 - Statements
 - Expressions
 - Declarations
- Categories are subdivided into more detailed categories
 - Loop-statement
 - If-statement
 - Logical-expression
 - ...
- Most programming language manuals include language grammar

```
<statement> -> <loop-statement>
<statement> -> <if-statement>
<loop-statement> -> for (<expression>; <expression>; <expression>
<expression> -> <logical-expression>
...
```

Syntax Analysis

- Parsing organizes tokens into a hierarchy called a *parse tree*
- A grammar of a language with the token stream defines the structure of the parse tree
- Syntax analysis is applied by a compiler to check the syntax program by constructing a parse tree of the program
- Example (incomplete) Pascal grammar:

```
<Program> -> program <id> ( <id> <More_ids> ) ; <Block> .
<Block> -> <Variables> begin <Stmnt> <More_Stmts> end
<More_ids> -> , <id> <More_ids>
          | e
<Variables> -> var <id> <More_ids> : <Type> ; <More_Variables>
          | e
<More_Variables> -> <id> <More_ids> : <Type> ; <More_Variables>
          | e
<Stmnt> -> <id> := <Exp>
          | read ( <id> <More_ids> )
          | writeln ( <Exp> <More_Exps> )
          | if <Exp> then <Stmnt> else <Stmnt>
          | while <Exp> do <Stmnt>
          | begin <Stmnt> <More_Stmts> end
```

Note: An interactive parser demo demonstrates the parsing of the gcd Pascal example program into a parse tree (see also textbook pp. 20-21)

Semantic Analysis

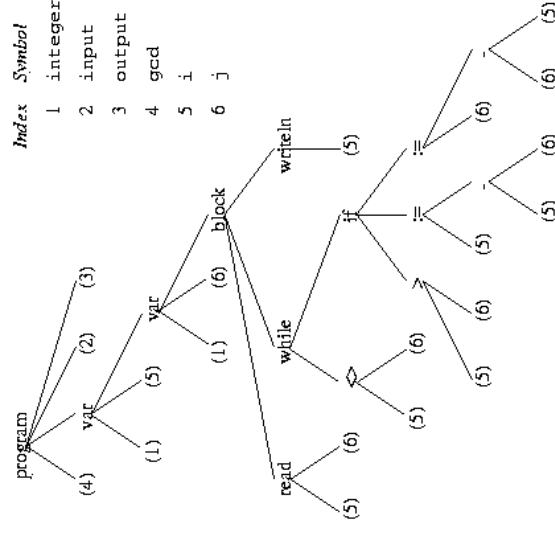
- Semantic analysis is applied by a compiler^[2] to discover the *meaning* of a program by analyzing its parse tree^[2] or abstract syntax tree^[2] (see later)
- *Static semantic checks*^[2] are performed at compile time
 - Type checking
 - Every variable is declared before used
 - Identifiers are used in appropriate contexts
 - Check subroutine call arguments
 - Check labels
- *Dynamic semantic checks*^[2] are performed at run time, and the compiler produces code that performs these checks
 - Array subscript values are within bounds
 - Arithmetic errors, e.g. division by zero
 - Pointers are not dereferenced unless pointing to valid object
 - A variable is used but hasn't been initialized
 - When a check fails at run time, an exception^[2] is raised

Strong Typing

- A language is strongly typed "if (type) errors are always detected"
- Such errors are listed on previous slide
- Errors are either detected at compile time or at run time
- Strong typing makes language safe and easier to use, but slow because of dynamic semantic checks
- Languages that are strongly typed are
 - Ada^[2]
 - Java^[2]
 - ML^[2], Haskell^[2]
- Languages that are *not* strongly typed are
 - Fortran^[2], Pascal^[2], C^[2]
 - Lisp^[2], C++^[2]
- In some languages, most (type) errors are detected late at run time which is detrimental to reliability (e.g. early Basic^[2], Lis Prolog^[2], some script languages)

Intermediate Code Generation

- A typical intermediate form of code produced by the semantic analyzer is an *abstract syntax tree (AST)*²
- The AST is *annotated* with useful information such as pointers to the symbol table entry of identifiers
- Example AST for the gcd Pascal program:



Target Code Generation and Optimization

- The AST with the annotated information is traversed by the compiler to generate a low-level intermediate form of code, close to assembly³
- This *machine-independent* intermediate form is optimized
- From the machine-independent form assembly or object code is generated by the compiler
- This *machine-specific* code is optimized to exploit specific hardware features