Fundamentals

Mitchell Chapter 4

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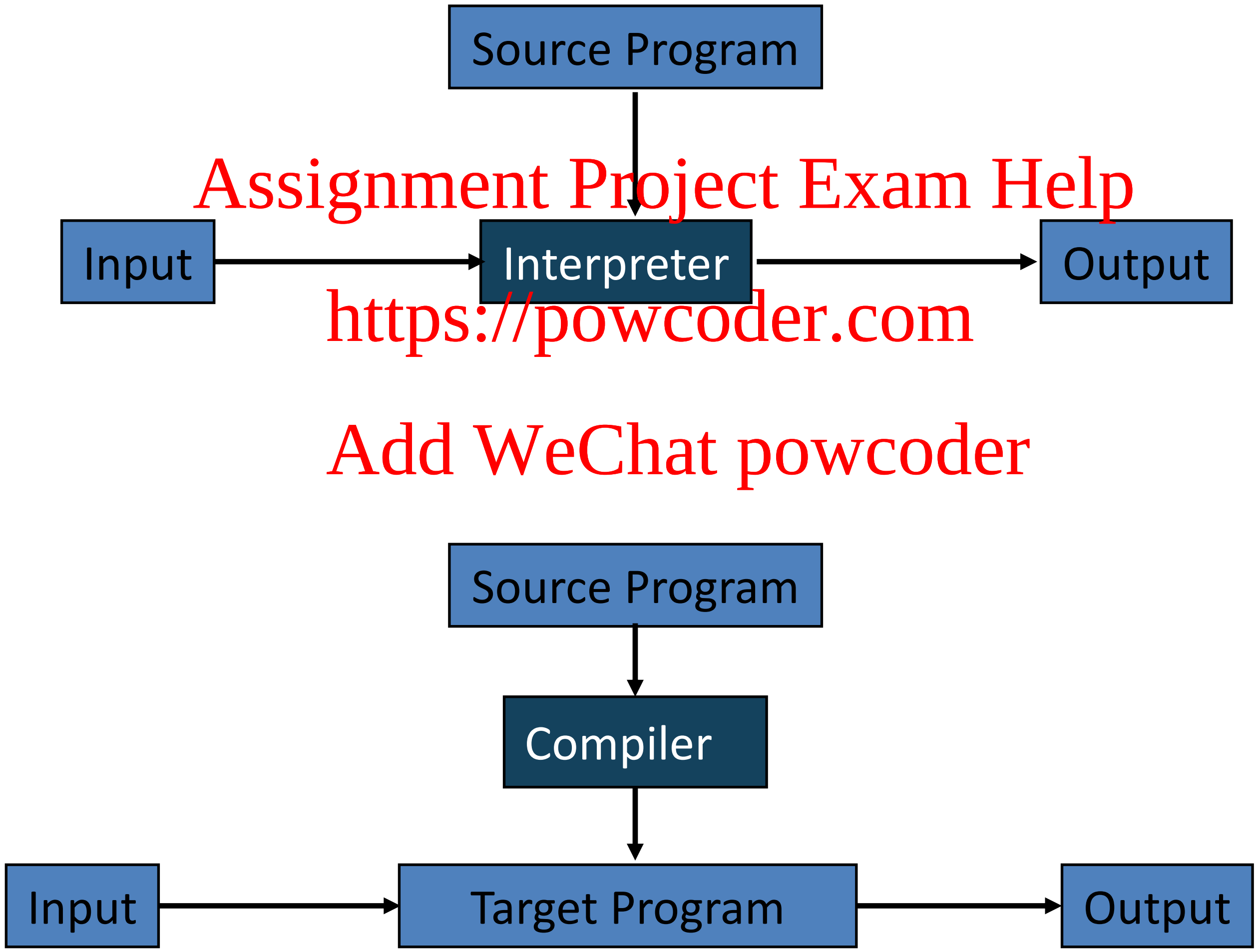
Syntax and Semantics of Programs

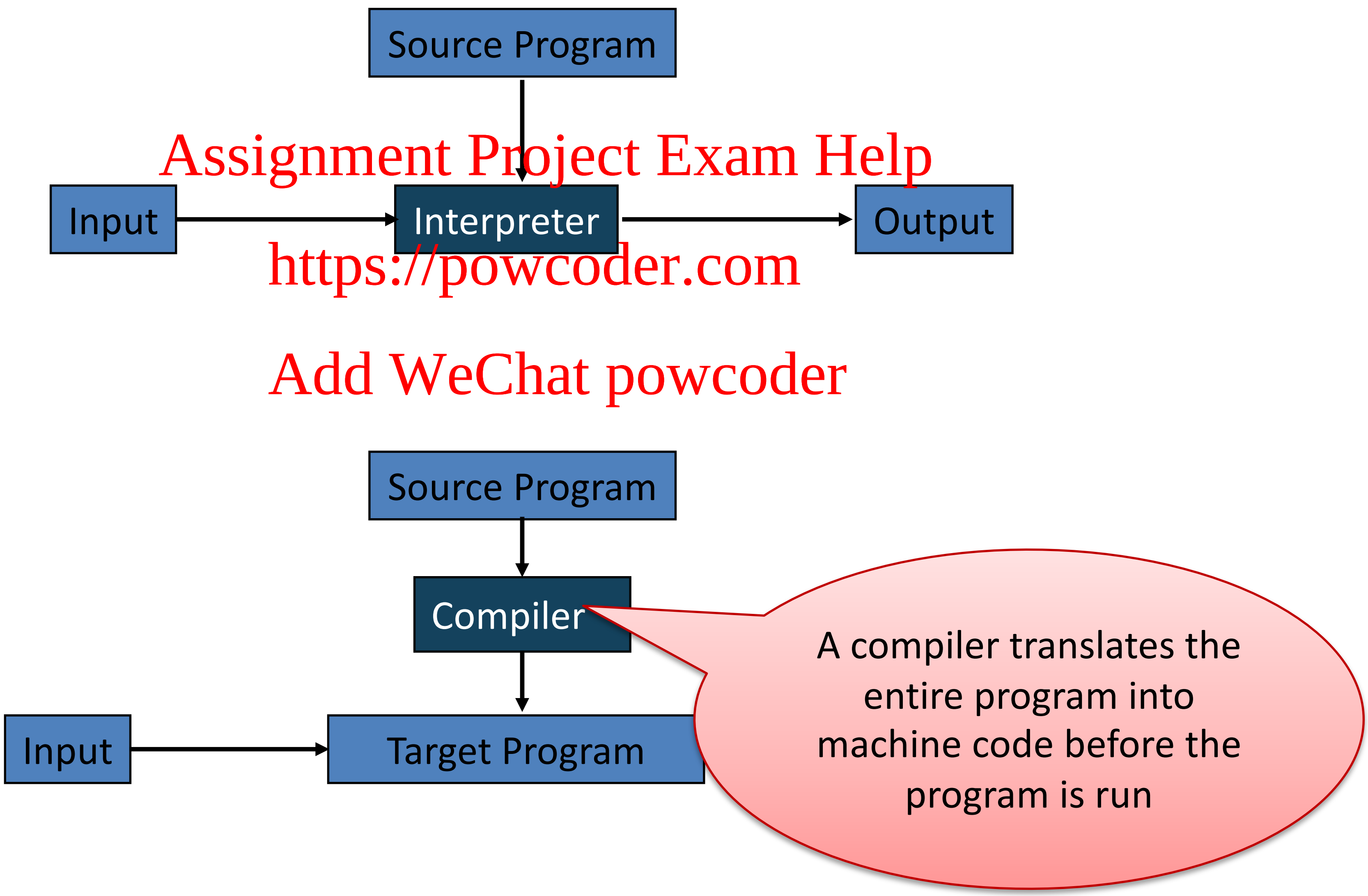
"…theoretical frameworks have had an impact on the design of programming languages and can be used to identify problem areas in programming languages."

- Syntax
  - The symbols used to write a program
- Semantics
  - The actions that occur when a program is executed
- Programming language implementation
  - Syntax → Semantics
  - Transform program syntax into machine instructions that can be executed to cause the correct sequence of actions to occur

Interpreters vs. Compilers



Interpreters vs. Compilers



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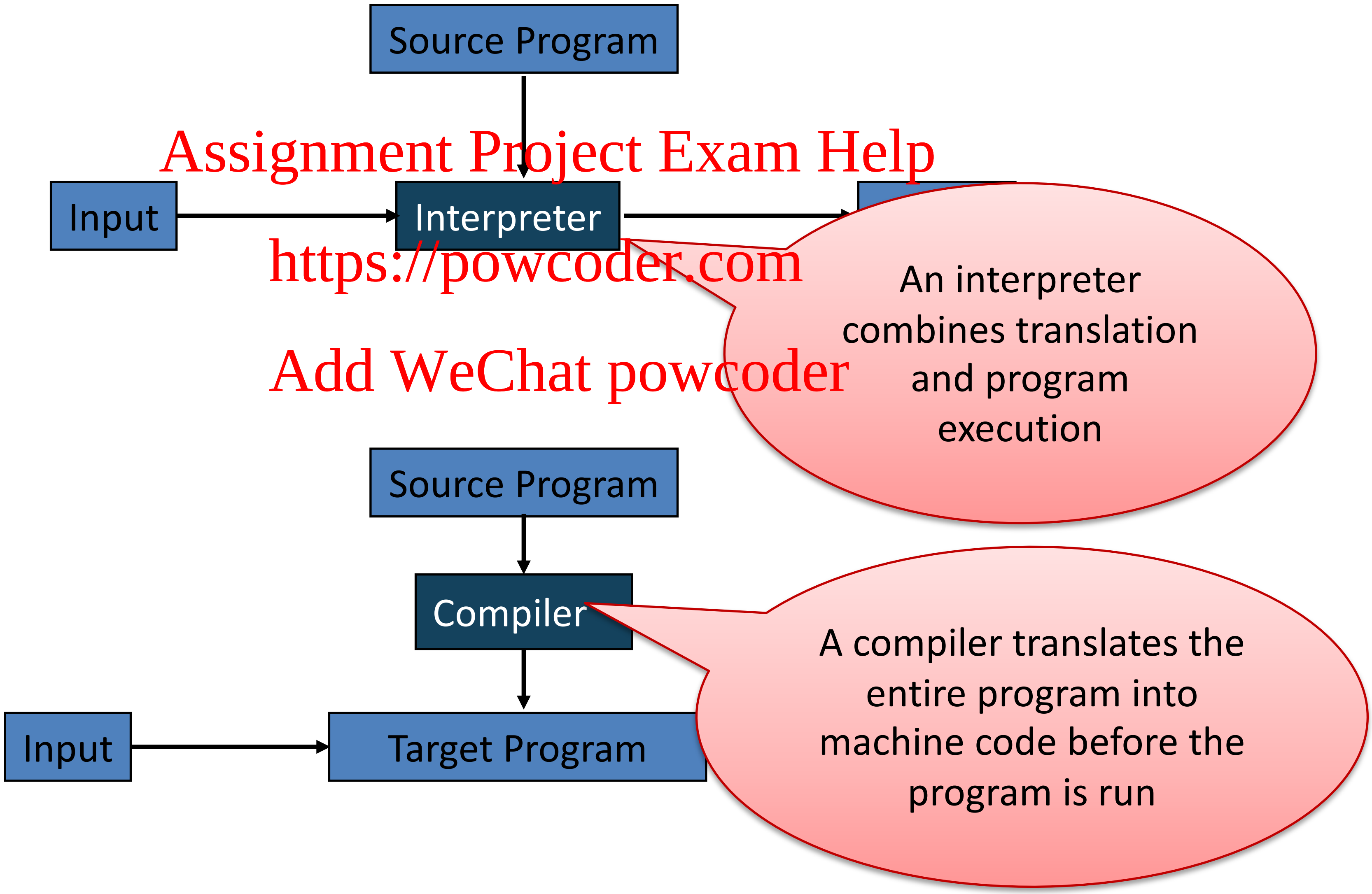
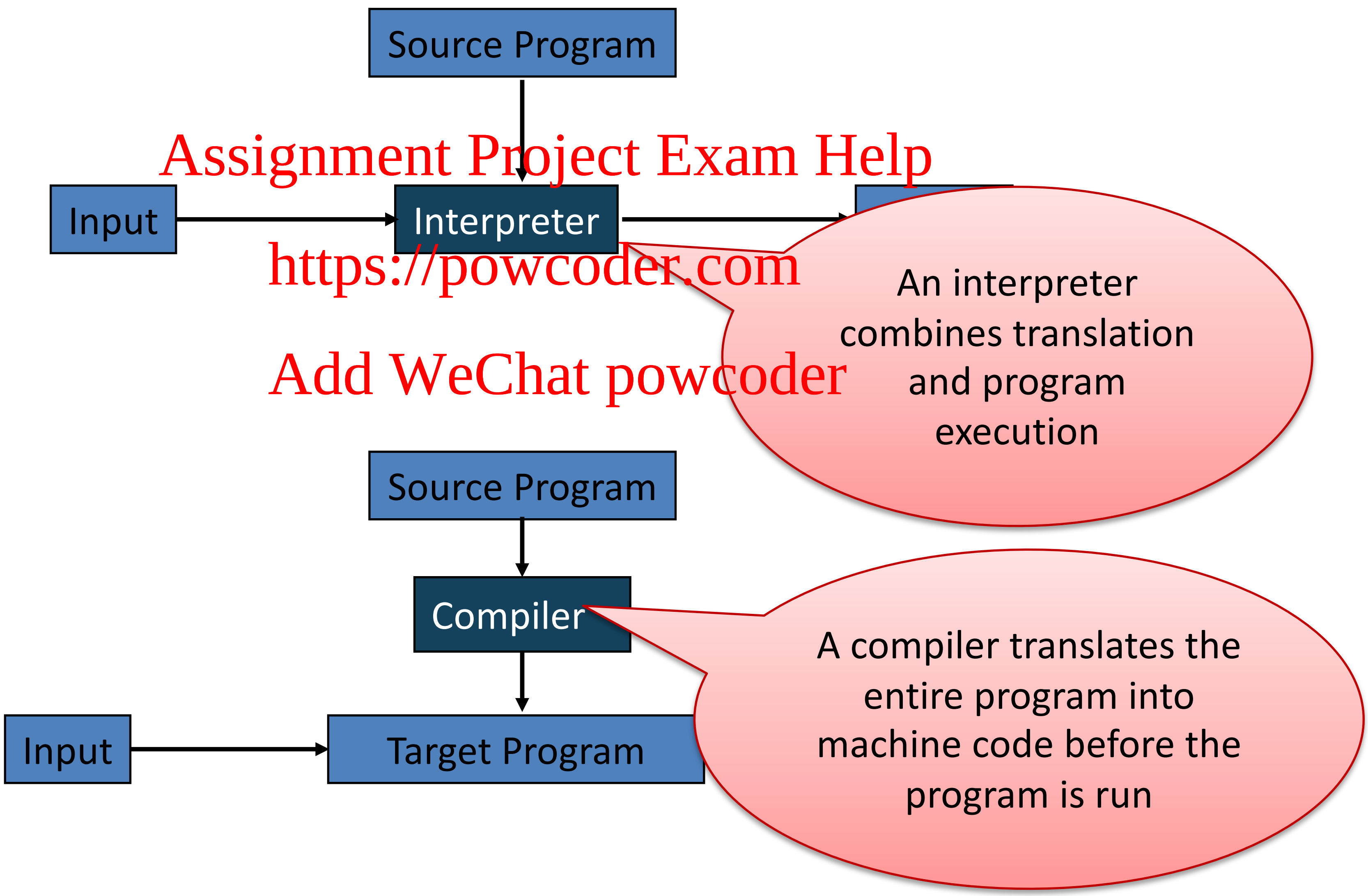
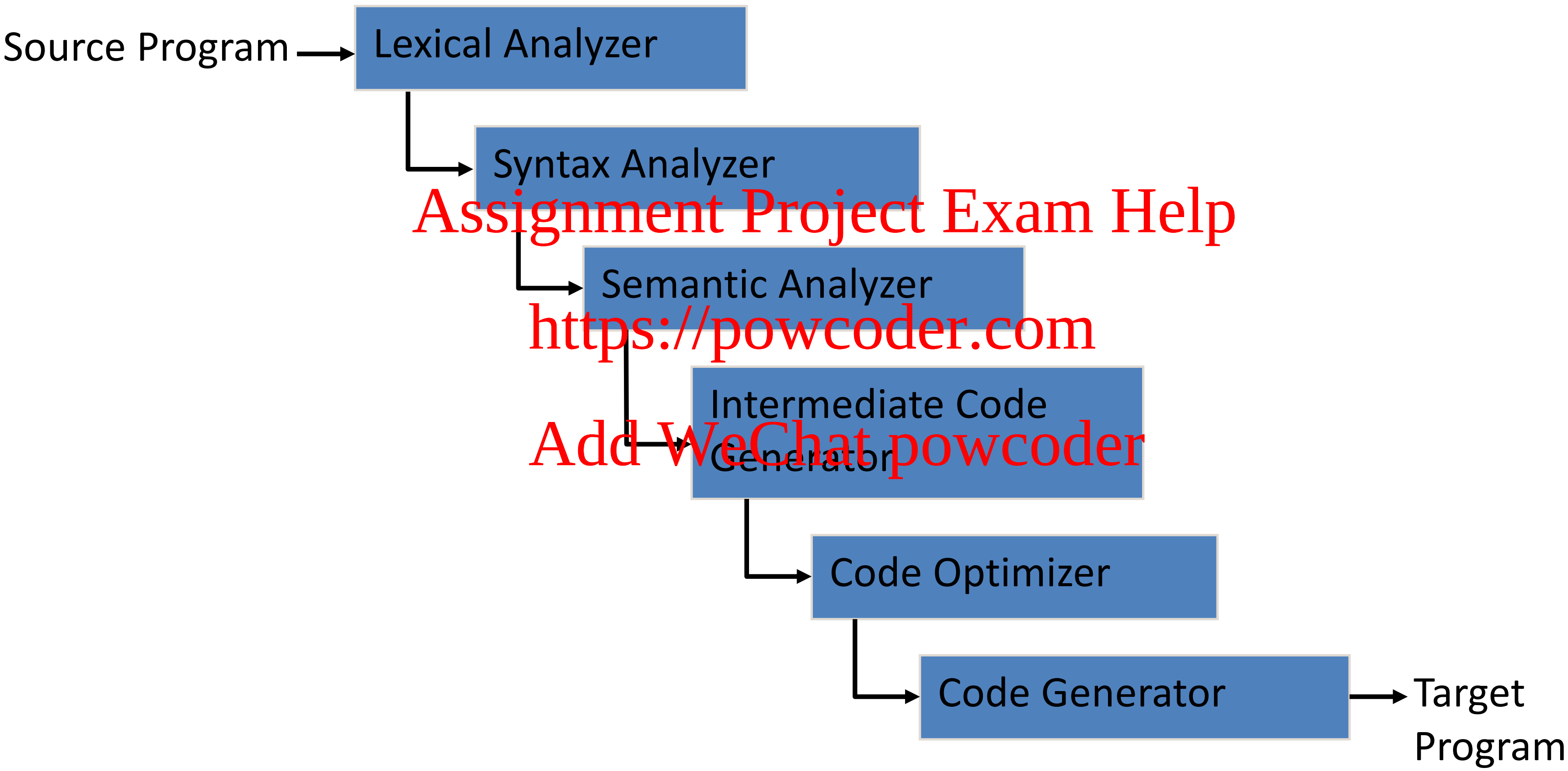


Interpreters vs. Compilers

Studying compilers makes it easier to separate the main issues and discuss them in a given order.



A Typical Compiler



Compiler Phases

- Lexical Analysis
  - Input symbols are scanned from left to right and grouped into meaningful units called *tokens*.
  - Distinguishes numbers, identifiers, symbols and keywords.
  - Example: temp := x+1

    Tokens are: temp, :=, x, +, 1

- Syntax Analysis

  - Parsing: tokens are grouped into syntactic units such as expressions, statements, and declarations that must conform to the grammatical rules of the programming language.

  - If the program does not meet the syntactic requirement to be a well-formed program, an error message is reported, and the compiler terminates.
  - The result is a parse tree.
  - To be discussed in more detail.

Compiler Phases

- Semantic Analysis
  - Context information is used to augment the parse tree, i.e., type information (from type inference)
  - Note the difference between semantic analysis and program semantics (i.e. program meaning)
- Intermediate Code Generation
  - It is difficult to generate efficient code in one phase.
  - It is important to use an intermediate representation that is easy to produce and easy to translate into the target language.
- Code Optimization
  - Different techniques are applied over and over to the intermediate representation. (See next page.)
- Code Generation
  - Converts the intermediate code into a target machine code.
  - Involves choosing memory locations and registers for variables.
  - Efficiency is important.

Some Standard Code Optimizations

- Common Subexpression Elimination
  - If a program calculates the same value more than once, then calculate only once and store for later use.
- Copy Propagation
  - If a program contains an assignment x=y then it may be possible to change later statements to refer to y instead of to x and remove the assignment.

- Dead-Code Elimination
  - Eliminate sequences of code that can never be reached.
- Loop Optimizations
  - Move expressions that occur inside a loop to outside the loop if they don’t change value.
- In-lining Function Calls
  - Substitute function calls with the body of the function when possible. This often allows further optimizations to be performed by removing jumps.

Syntax: Grammars and Parse Trees

- Grammar

  e ::= n | e+e | e–e

  n ::= d | nd

  d ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

- Expressions in language generated by *derivations*, e.g.,

e → e–e

→ e–e+e → n–n+n → nd–d+d → dd–d+d

→ … → 27 – 4 + 3

Grammar defines a language

Expressions in language derived by sequence of productions

Syntax: Grammars and Parse Trees

- Grammar

  e ::= n | e+e | e–e

  n ::= d | nd

  d ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

- A Grammar includes:
  - A *start symbol* (e in this case)
  - A set of *nonterminals*
  - A set of *terminals* (which appear in the expressions of the language generated by the grammar)

- In this example:
  - Nonterminals: e, n, d
  - Terminals: 0,…9,+, –
- Examples:
  - 0, 1+3+5, 2+4-6-8

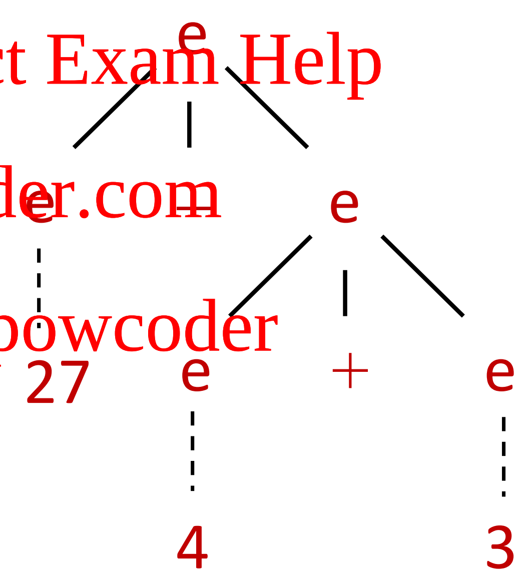
Nonterminals keep track as a valid expression is being formed. They must eventually be replaced.

Parse Trees (Derivation Trees)

- Derivation represented by tree

  $e \rightarrow e{-}e \rightarrow e{-}e{+}e \rightarrow n{-}n{+}n \rightarrow nd{-}d{+}d \rightarrow dd{-}d{+}d$

  $\rightarrow \ldots \rightarrow 27 - 4 + 3$



Tree shows parenthesization of expression.
A grammar is *ambiguous* if some expression
has more than one parse tree.

Parse Trees (Derivation Trees)

- Exercise: draw 2 parse trees for 10—15 + 12

- Grammar

  s ::= v:=e | s;s | if b then s | if b then s else s

  v ::= x | y | z

  e ::= v | 0 | 1 | 2 | 3 | 4

  b ::= e=e

- Exercise: draw 2 parse trees for

  if b1 then if b2 then s1 else s2

  What happens when b1=true and b2=false?

Mitchell, pp. 54-55

Parsing

- Parsing
  - Given a language *L* defined by a grammar *G*, and a string of symbols *s*, an algorithm that decides whether *s* is in *L*, and constructs a parse tree if it is, is called a *parsing algorithm* for *G*.
- Ambiguity

  - Expression 27 – 4 + 3 can be parsed two ways
  - Problem: 27 – (4 + 3) ≠ (27 – 4) + 3

- Ways to resolve ambiguity

  - Precedence
    - By convention * has higher *precedence* than + or —
    - For example, parse 3*4 + 2 as (3*4) + 2
  - Associativity
    - Parenthesize operators of equal precedence to left (or right)
    - Parse 3 – 4 + 5 as (3 – 4) + 5