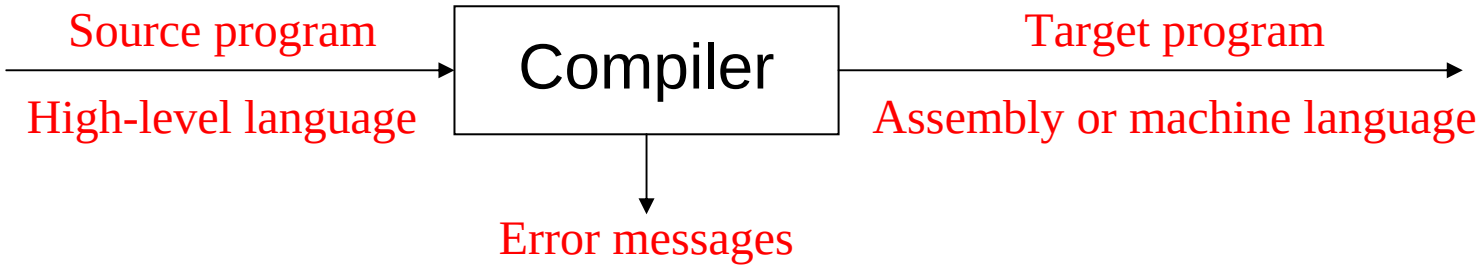
# What is a Compiler? Read Chapter 1

- Is a program that translates one language to another
  - Takes as input a source program typically in a high-level language
  - Produces an equivalent target program in assembly or machine language
  - Reports error messages as part of the translation process




- First computers of late 1940s were programmed in machine language
- Machine language was soon replaced by assembly language
  - Instructions and memory locations are given symbolic names
  - An assembler translates the symbolic assembly code into equivalent machine code
  - Assembly language improved programming, but is still machine dependent

# Brief History

- The term “compiler” was coined in the early 1950s by Grace Murray Hopper
  - Translation was viewed as the “compilation” of a sequence of library routines
- First compiler was for the high-level language FORTRAN
  - Developed between 1954 and 1957 at IBM by a group led by John Backus
  - Proved the viability of high-level and thus less machine dependent languages
- The study of scanning and parsing were pursued in the 1960s and 1970s
  - Led fairly to a complete solution
  - Became standard part of compiler theory
  - Resulted in scanner and parser generators that automate part of compiler development
- Methods of generating efficient target code is still an ongoing research
  - Known as optimization or code improvement techniques
- Compiler technology was also applied in rather unexpected areas:
  - Text-formatting languages
  - Hardware description languages for the automatic creation of VLSI circuits

# The Translation Process

- A compiler performs two major tasks:
  - Analysis of the source program
  - Synthesis of the target-language instructions

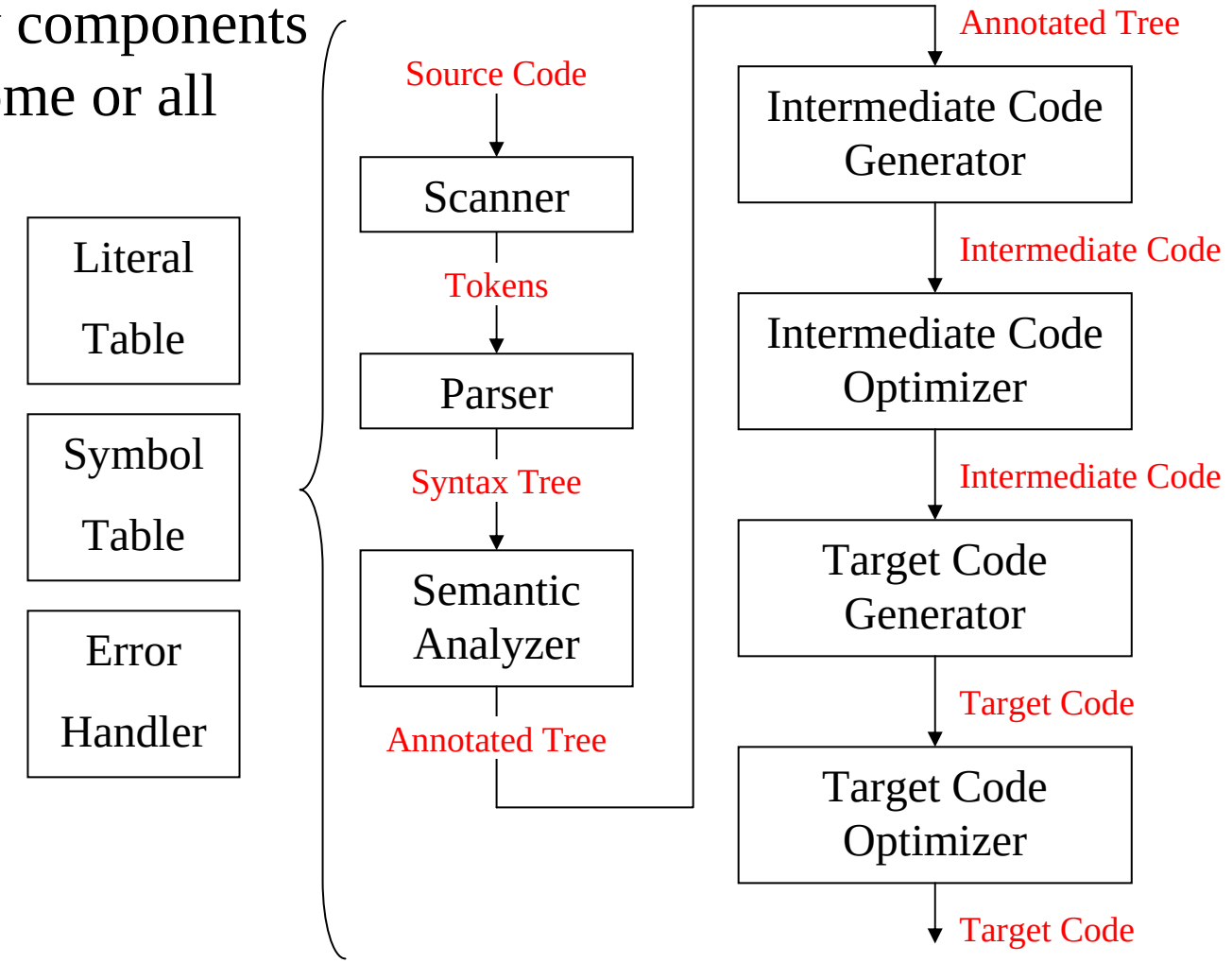
- Phases of a compiler:
  - Scanning
  - Parsing
  - Semantic Analysis
  - Intermediate Code Generation
  - Intermediate Code Optimization
  - Target Code Generator
  - Target Code Optimization

Mainly Analysis

Mainly Synthesis

# The Translation Process – Cont'd

- Three auxiliary components interact with some or all phases:
  - Literal Table
  - Symbol Table
  - Error Handler



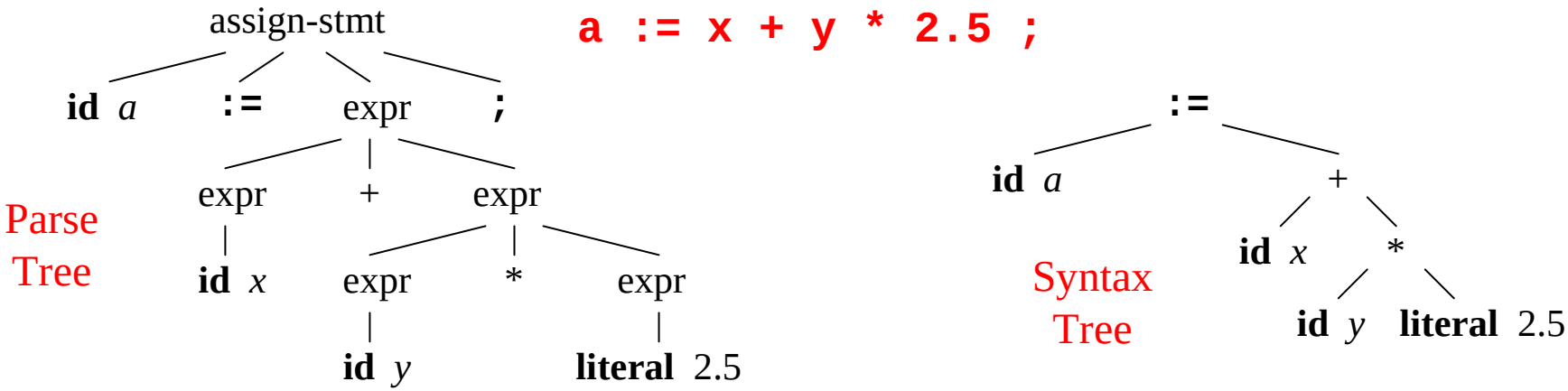
# Scanner

- The scanner begins the analysis of the source program by:
  - Reading file character by character
  - Grouping characters into tokens
  - Eliminating unneeded information (comments and white space)
  - Entering preliminary information into literal or symbol tables
  - Processing compiler directives by setting flags
- Tokens represent basic program entities such as:
  - Identifiers, Literals, Reserved Words, Operators, Delimiters, etc.
- Example: `a := x + y * 2.5 ;` is scanned as

| | | | |
|---|---|---|---|
| `a` | identifier | `y` | identifier |
| `:=` | assignment operator | `*` | multiplication operator |
| `x` | identifier | `2.5` | real literal |
| `+` | plus operator | `;` | semicolon |

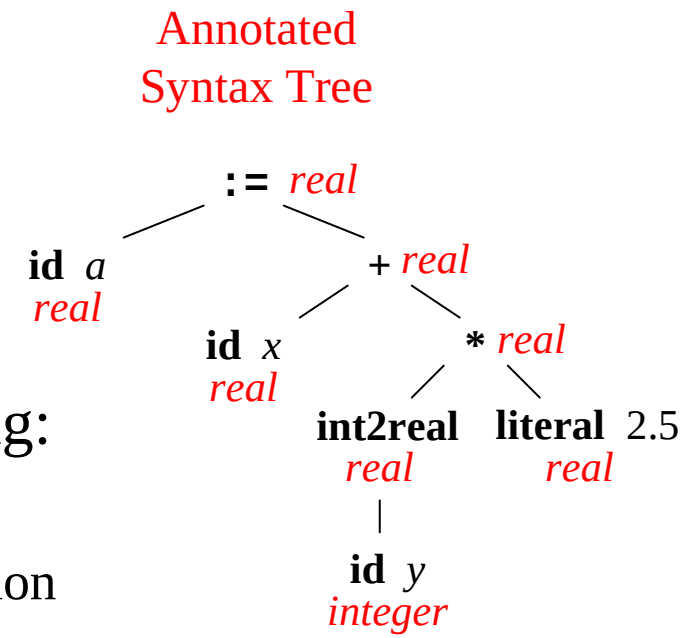
# Parser

- Receives tokens from the scanner
- Recognizes the structure of the program as a **parse tree**
  - Parse tree is recognized according to a context-free grammar
  - Syntax errors are reported if the program is syntactically incorrect
- A parse tree is inefficient to represent the structure of a program
- A **syntax tree** is a more condensed version of the parse tree
- A syntax tree is usually generated as output of the parser



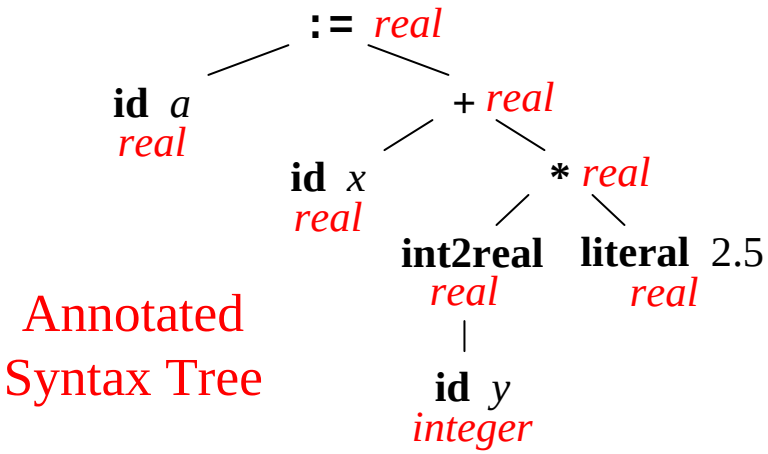
# Semantic Analyzer

- The semantic of a program is its meaning as opposed to structure
- Semantics consist of:
  - Runtime semantics – behavior of program at runtime
  - Static semantics – checked by the compiler
- Static semantics include:
  - Declarations of variables before use
  - Calling functions that exist
  - Passing parameters properly
  - Type checking
- The semantic analyzer does the following:
  - Checks the static semantics of the language
  - Annotates the syntax tree with type information



# Intermediate Code Generator

- Comes after syntax and semantic analysis
- Separates the compiler front end from its backend
- Intermediate representation should have 2 important properties:
  - Should be easy to produce
  - Should be easy to translate into the target language
- Intermediate representation can have a variety of forms:
  - Three-address code, P-code, Tree or DAG representation




Annotated Syntax Tree

Three-address code

```
temp1 := int2real(y)
temp2 := temp1  real*  2.5
temp3 := x  real+  temp2
a := temp3
```

# Code Generator

- Generates code for the target machine, typically:
  - Assembly code, or
  - Relocatable machine code
- Properties of the target machine become a major factor
- Code generator selects appropriate machine instructions
- Allocates memory locations for variables
- Allocates registers for intermediate computations

Three-address code

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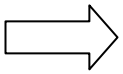


Assembly code (Hypothetical)

```
LOADI   R1 = [y]        ;; R1 ← MEM[y]
CI2F    F1 = R1         ;; F1 ← int2real(y)
MOVF    F2 = 2.5        ;; F2 ← 2.5
MULF    F3 = F1, F2     ;; F3 ← int2real(y) * 2.5
LOADF   F4 = [x]        ;; F4 ← MEM[x]
ADDF    F5 = F4, F3     ;; F5 ← x + int2real(y) * 2.5
STOREF  [a] = F5        ;; MEM[a] ← F5
```

# Code Improvement

- Code improvement techniques can be applied to:
  - Intermediate code – independent of the target machine
  - Target code – dependent on the target machine
- Intermediate code improvement include:
  - Constant folding
  - Elimination of common sub-expressions
  - Identification and elimination of unreachable code (called dead code)
  - Improving loops
  - Improving function calls
- Target code improvement include:
  - Allocation and use of registers
  - Selection of better (faster) instructions and addressing modes

# Passes

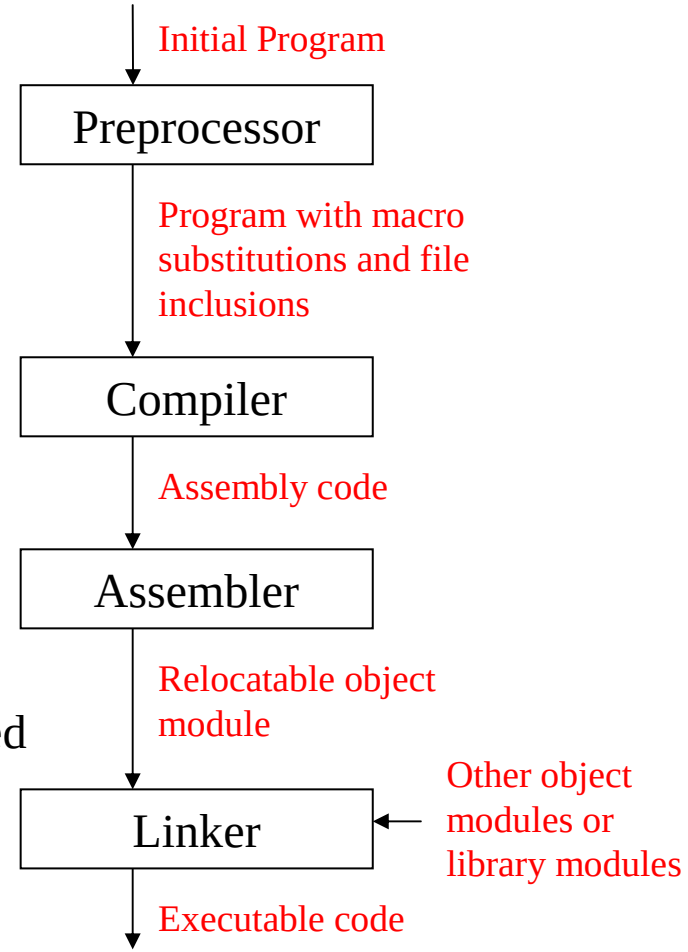
- A compiler may traverse a program several times to generate code
- Each traversal is called a pass
- Passes may or may not correspond to phases
- A one-pass compiler overlaps all phases in a single pass
  - Languages, such as C and Pascal, permit one-pass compilation
  - Compilation is efficient; a small chunk of the program is translated at a time
  - Resulting code is inefficient because optimizations require additional passes
- A multi-pass compiler holds transformed program between passes
  - Some languages require more than one pass to be translated properly
  - A first pass may construct the syntax tree from source program
  - A second pass may do semantic analysis
  - A third pass may generate code
  - Additional passes may do optimizations

# Interpreter

- Is a program that reads a source program and executes it
- Works by analyzing and executing the source program commands *one at a time*
- Does not translate the source program into object code
- Interpretation is sensible when:
  - Programmer is working in interactive mode and needs to view and update variables
  - Running speed is not important
  - Commands have simple formats, and thus can be quickly analyzed and executed
  - Modification or addition to user programs is required as execution proceeds
- Well-known examples of interpreters:
  - BASIC interpreter, LISP interpreter, UNIX shell interpreter, SQL interpreter
- In principle, any programming language can be either interpreted or compiled
  - Some languages are designed to be interpreted, others are designed to be compiled
- Interpreters involve large overheads
  - Execution speed degradation can vary from 10:1 to 100:1
  - Substantial space overhead may be involved

# Programs Related to Compilers

- Preprocessor
  - Produces input to a compiler
  - Performs the following:
    - Macro processing (substitutions)
    - File inclusion
- Assembler
  - Translator for the assembly language
  - Two-Pass Assembly:
    - All variables are allocated storage locations
    - Assembler code is translated into machine code
  - Output is relocatable machine code
- Linkers
  - Links object files separately compiled or assembled
  - Links object files to standard library functions
  - Generates a file that can be loaded and executed
- Debuggers
- Editors



# Major Data and Structures in a Compiler

- Token
  - Represented by an integer value or an enumeration literal
  - Sometimes, it is necessary to preserve the string of characters that was scanned
    - For example, name of an identifier or value of a literal
- Syntax Tree
  - Constructed as a pointer-based structure
  - Dynamically allocated as parsing proceeds
  - Nodes have fields containing information collected by the parser and semantic analyzer
- Symbol Table
  - Keeps information associated with all kinds of identifiers:
    - Variables, functions, parameters, types, fields, etc.
  - Identifiers are entered by the scanner, parser, or semantic analyzer
  - Semantic analyzer adds type information and other attributes
  - Code generation and optimization phases use the information in the symbol table
  - Insertion and search operations should be efficient because they are frequent
  - Hash table with constant-time operations is usually the preferred choice

# Major Data and Structures in a Compiler – cont'd

- Literal Table
  - Stores constant values and string literals in a program
  - One literal table applies globally to the entire program
  - Used by the code generator to:
    - Assign addresses to literals
    - Enter data definitions in the target code file
  - Avoids the replication of constants and strings
  - Quick insertion and lookup are essential
  - Deletion is not necessary
- Temporary Files
  - Used historically by old compilers due to memory constraints
  - Hold the data of various stages