Compilers

- 40-414: Compiler Design

  http://sharif.edu/~sani/courses/compiler/

- Computer Engineering Dept., Sharif University

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Compilers

- **Lectures:**
  - **Time: Sundays and Tuesdays, 16:30-18:00**
  - **Location:** https://vc.sharif.edu/ch/sani, or https://vclass.ecourse.sharif.edu/ch/sani
- **Evaluation:**

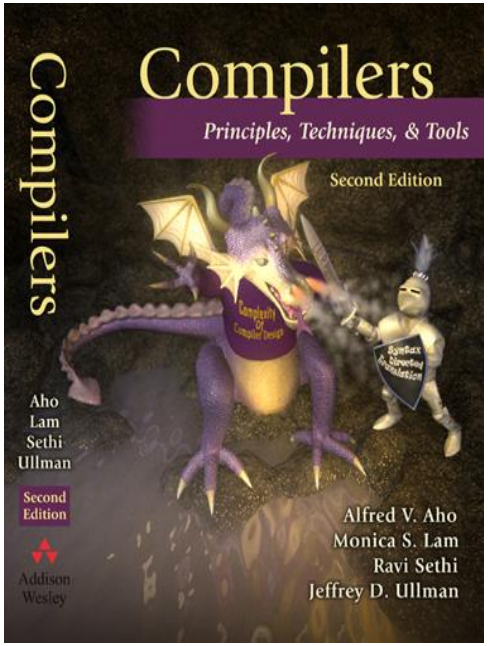
4 Written Assignments, and	20%
4 Programming Assignments	40%
2 Exams	40%

Acknowledgement

- Most Lecture Notes are from a similar course (i.e., CS-143) taught by Professor Alex Aiken in Stanford University

Text

- The Purple Dragon Book
- Aho, Lam, Sethi & Ullman
- Not required
  - But a useful reference



The Course Project

- A big project
- … in 4 rather easy parts
- Start early!

Academic Honesty

- Don’t use work from uncited sources
  - Including old code
- We use plagiarism detection software
  - many cases in past offerings

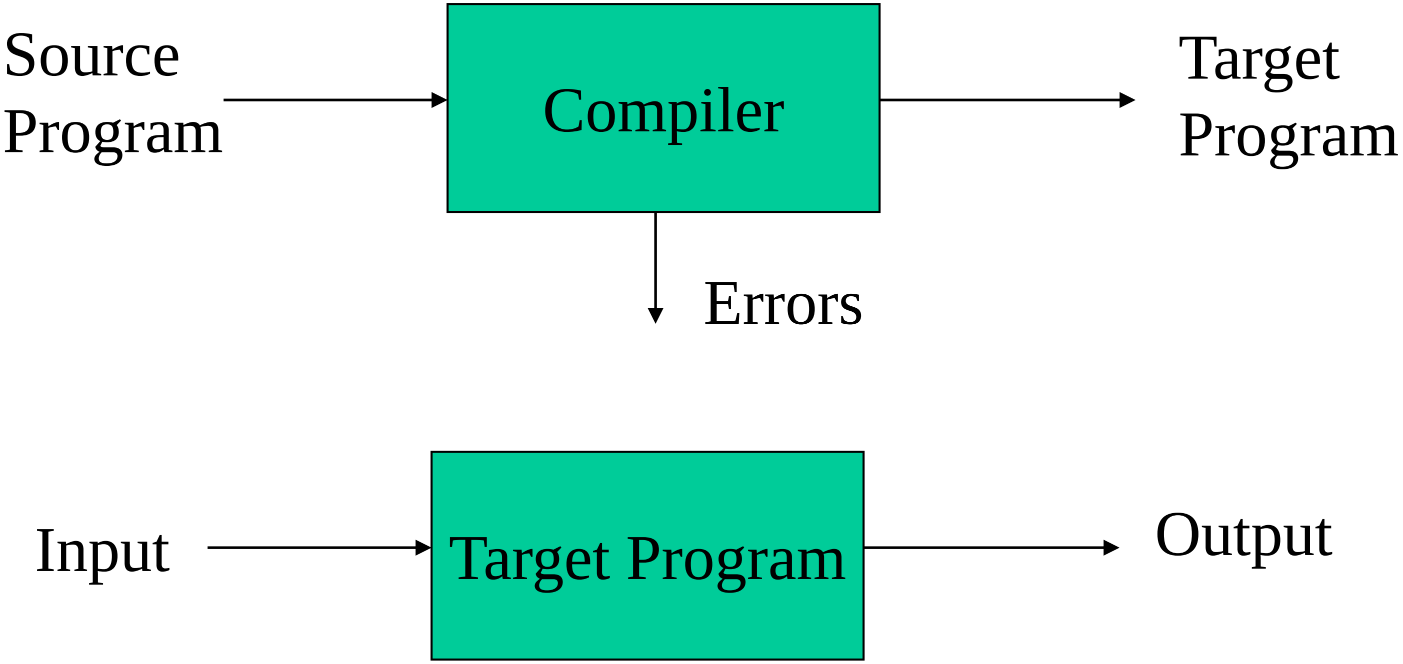
How are Languages Implemented?

- Two major strategies:
  - Interpreters (older)
  - Compilers (newer)

- Interpreters run programs “as is”
  - Little or no preprocessing

- Compilers do extensive preprocessing

Compilers



Source Program

Compiler

Target Program

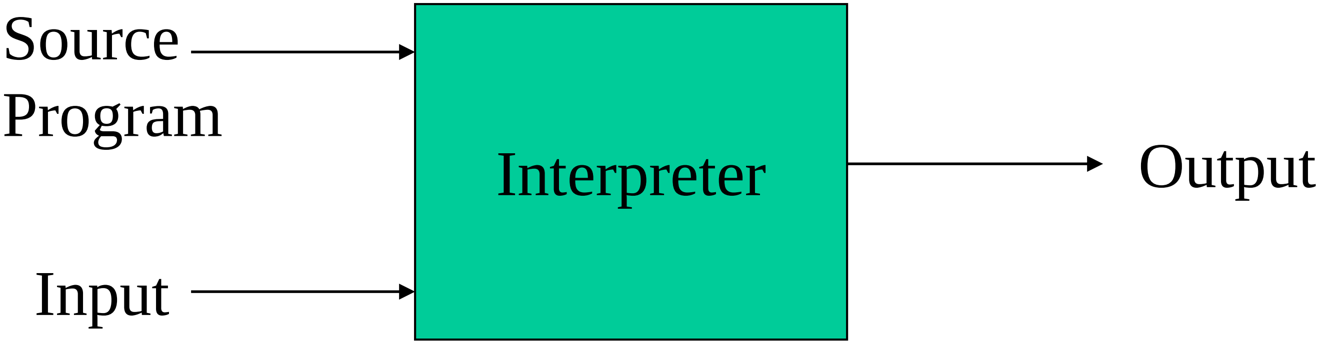
Errors

Input

Target Program

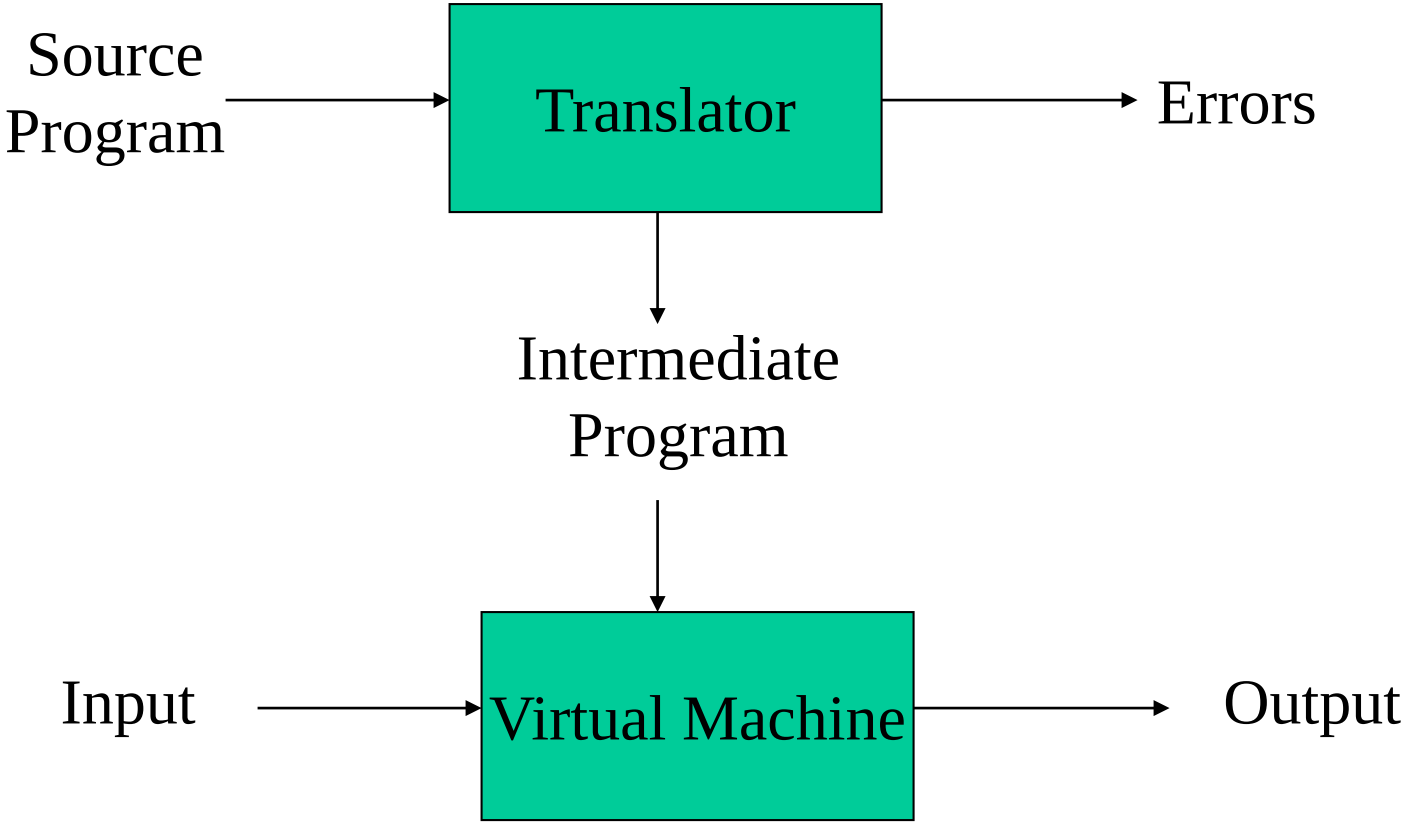
Output

Interpreters



- Translates line by line
- Executes each translated line immediately
- Execution is slower because translation is repeated

A Hybrid Compiler



Source Program

Translator

Errors

Intermediate Program

Input

Virtual Machine

Output

Different Types of Compilers

Construction
- **Single Pass**
- **Multiple Pass**

History of Compilers

- 1954 IBM develops the 704
  - Successor to the 701

- Problem
  - Software costs exceeded hardware costs!
- All programming done in assembly

The Solution

- “Speedcoding”

- an early example of an interpreter
- developed in 1953 by John Backus
- much faster way of developing programs
- programs were 10-20 times slower than hand-written assembly
- needed 300 bytes = 30% machine memory

John Backus

FORTRAN I

- FORmula TRANslation Project
- FORTRAN ran from 1954 To 1957
- By 1958, over 50 percent of all of programs were in FORTRAN

John Backus

FORTRAN I

- The first compiler
  - Huge impact on computer science

- Led to an enormous body of theoretical work

- Modern compilers preserve the outlines of FORTRAN I

The Structure of Fortran Compiler

1. Lexical Analysis
2. Parsing
3. Semantic Analysis
4. Optimization
5. Code Generation

The first 3, at least, can be understood by analogy to how humans comprehend English.

Lexical Analysis

- First step: recognize words.
  - Smallest unit above letters

This is a sentence.

More Lexical Analysis

- Lexical analysis is not trivial. Consider:

ist his ase nte nce

And More Lexical Analysis

- Lexical analyzer divides program text into "words" or "tokens"

  If x == y then z = 1; else z = 2;

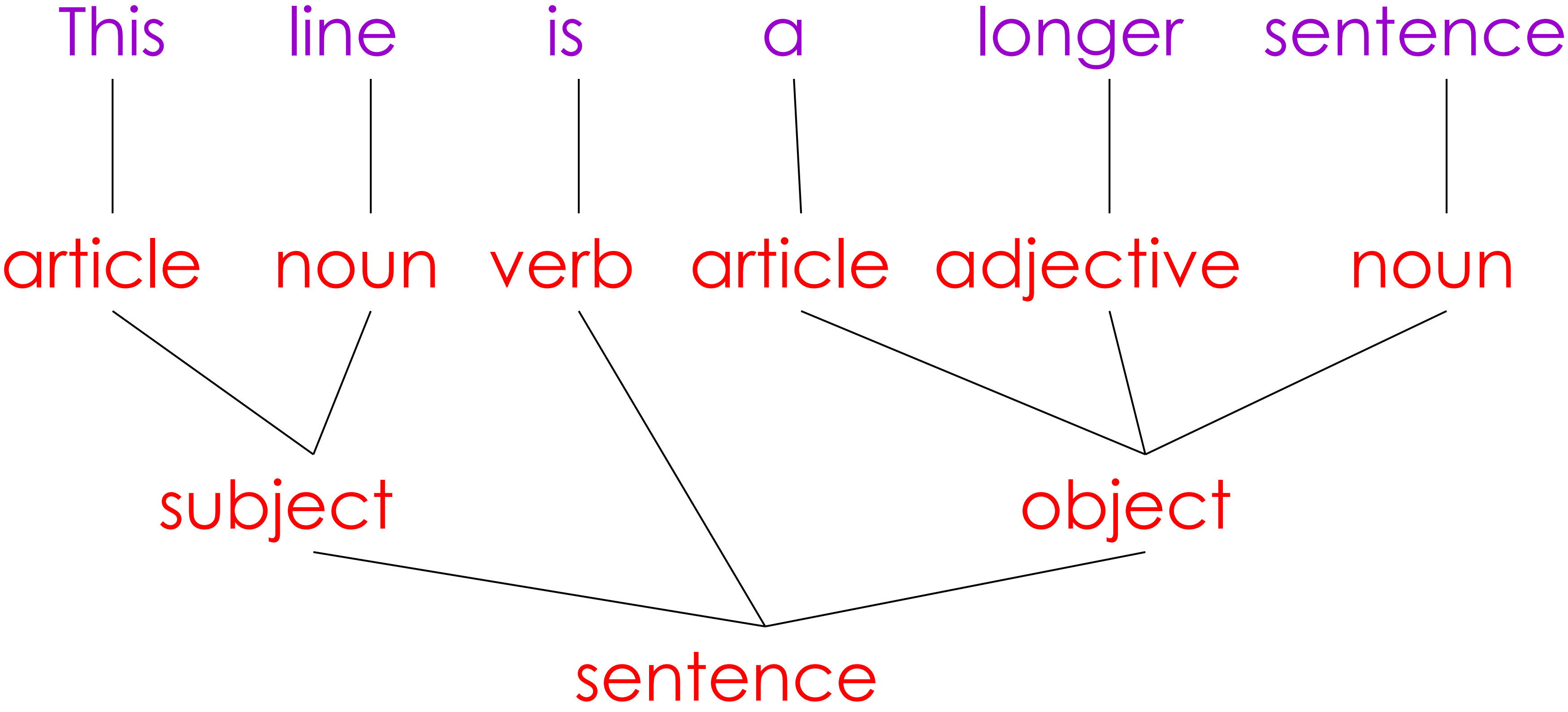
- Units:
  - Keywords { if, then, else }
  - Identifiers { x, y, z }
  - Numbers { 1, 2 }
  - Operators { ==, = }
  - Separators { blanks, ; }

Parsing

- Once words are understood, the next step is to understand sentence structure

- Parsing = Diagramming Sentences
  - The diagram is a tree

Diagramming a Sentence



This line is a longer sentence

article noun verb article adjective noun

subject object

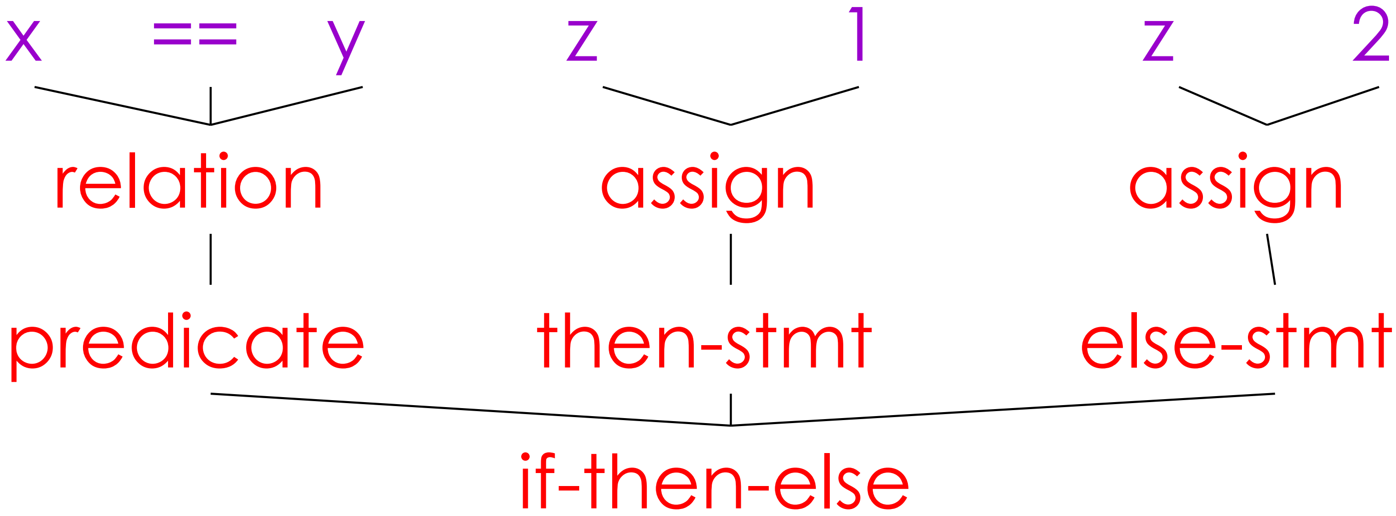
sentence

Parsing Programs

- Parsing program expressions is the same
- Consider:

If x == y then z = 1; else z = 2;

- Diagrammed:



Semantic Analysis

- Once sentence structure is understood, we can try to understand "meaning"
  - But meaning is too hard for compilers

- Compilers perform limited semantic analysis to catch inconsistencies

Semantic Analysis in English

- Example:

  Jack said Jerry left his assignment at home.

  What does "his" refer to? Jack or Jerry?

- Even worse:

  Jack said Jack left his assignment at home?

  How many Jacks are there? (1, 2 , or 3)

  Which one left the assignment?

Semantic Analysis in Programming

- Programming languages define strict rules to avoid such ambiguities
- This C++ code prints "4"; the inner definition is used

```
{
  int Jack = 3;
  {
     int Jack = 4;
     cout << Jack;
  }
}
```

More Semantic Analysis

- Compilers perform many semantic checks besides variable bindings

- Example:

  Jack left her homework at home.

- A "type mismatch" between her and Jack; we know they are different people
  - Presumably Jack is male

Optimization

- No strong counterpart in English,
  - but a little bit like editing
  - but akin to editing
- Automatically modify programs so that they
  - Run faster
  - Use less memory
- Your project has no optimization component :D

Optimization Example

$X = Y * 0$ is the same as $X = 0$

NOT ALWAYS CORRECT

NaN

NaN * 0 = NaN

Code Generation

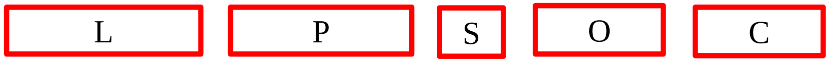
- Produces assembly code (usually)

- A translation into another language
  - Analogous to human translation

Compilers Today

- The overall structure of almost every compiler adheres to our outline

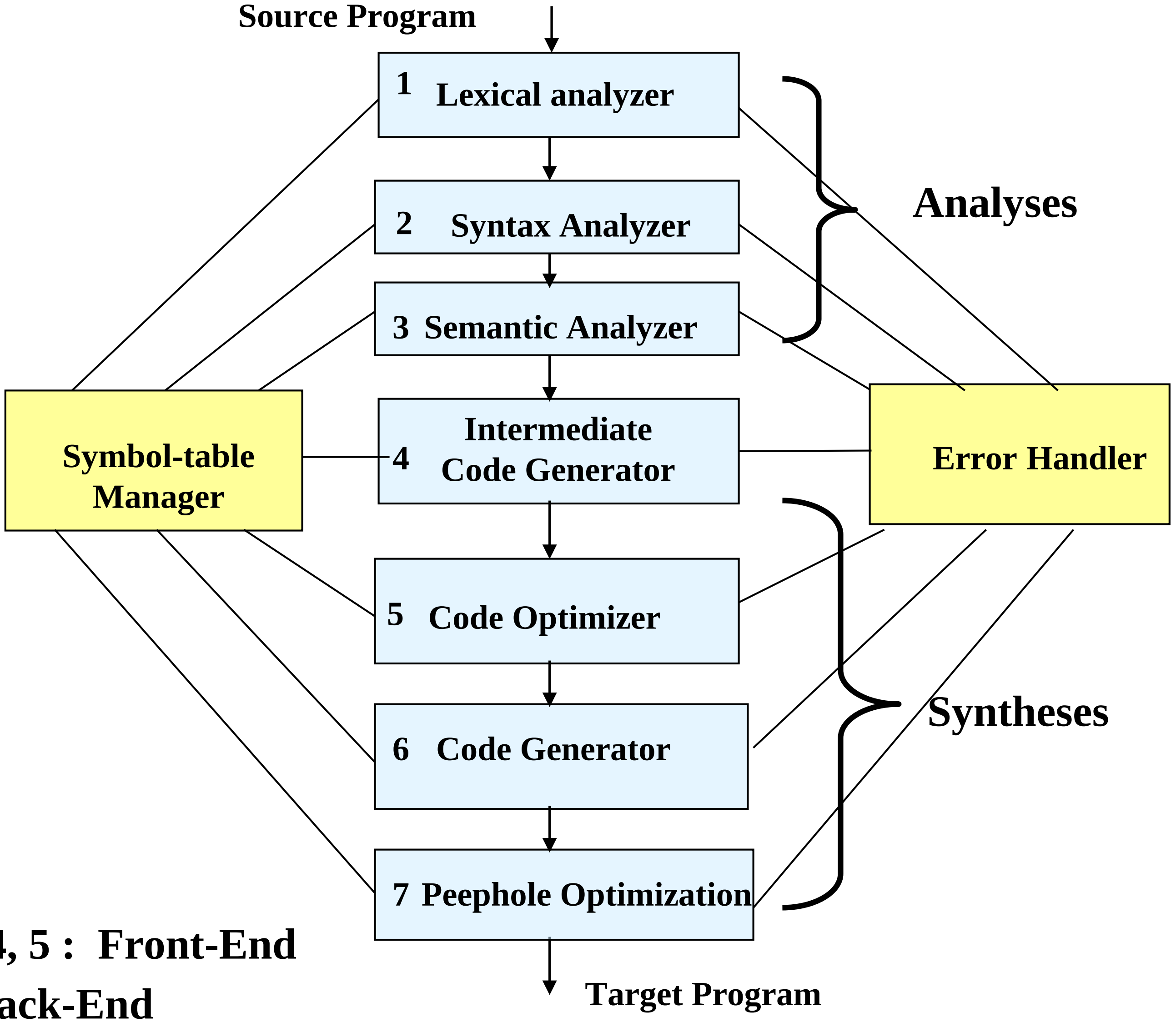
- The proportions have changed since FORTRAN
  - Early: lexing, parsing most complex, expensive


L P S O C

  - Today: optimization dominates all other phases, lexing and parsing are cheap


L P S O C

Compiler Front-end and Back-end



Source Program

1 Lexical analyzer

2 Syntax Analyzer

3 Semantic Analyzer

4 Intermediate Code Generator

5 Code Optimizer

6 Code Generator

7 Peephole Optimization

Target Program

Symbol-table Manager

Error Handler

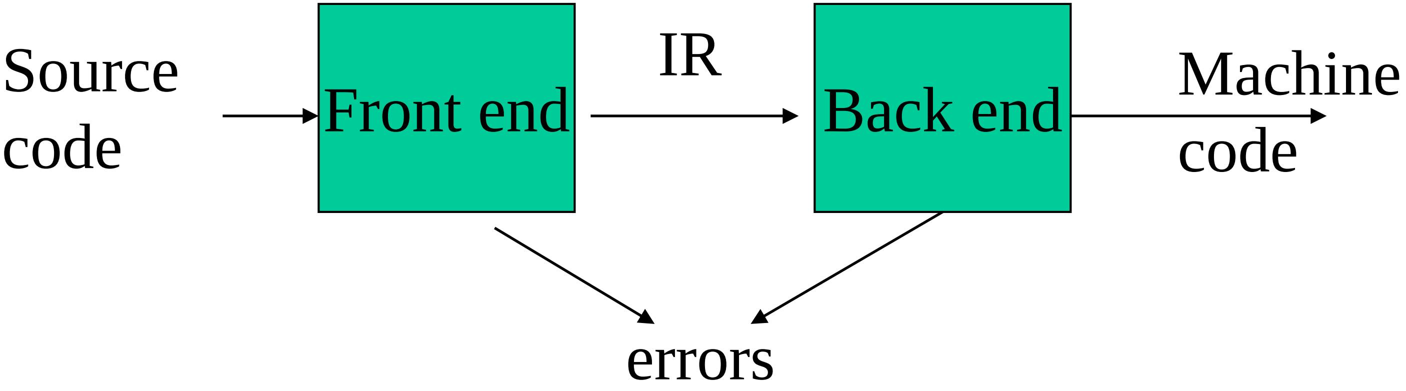
Analyses

Syntheses

1, 2, 3, 4, 5 : Front-End

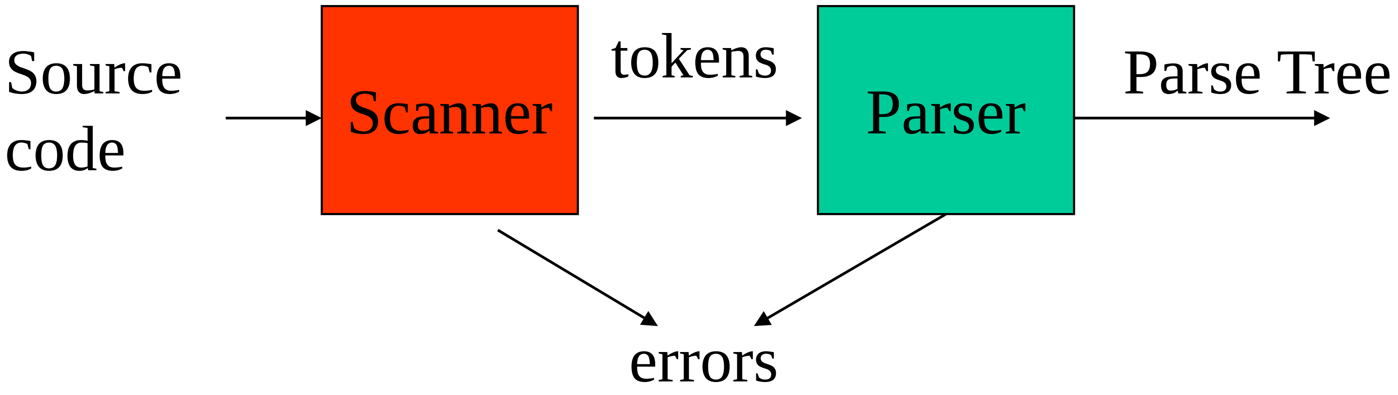
6, 7 : Back-End

Front-End



- Front end maps source code into an IR representation
- Back end maps IR onto machine code
- Simplifies retargeting

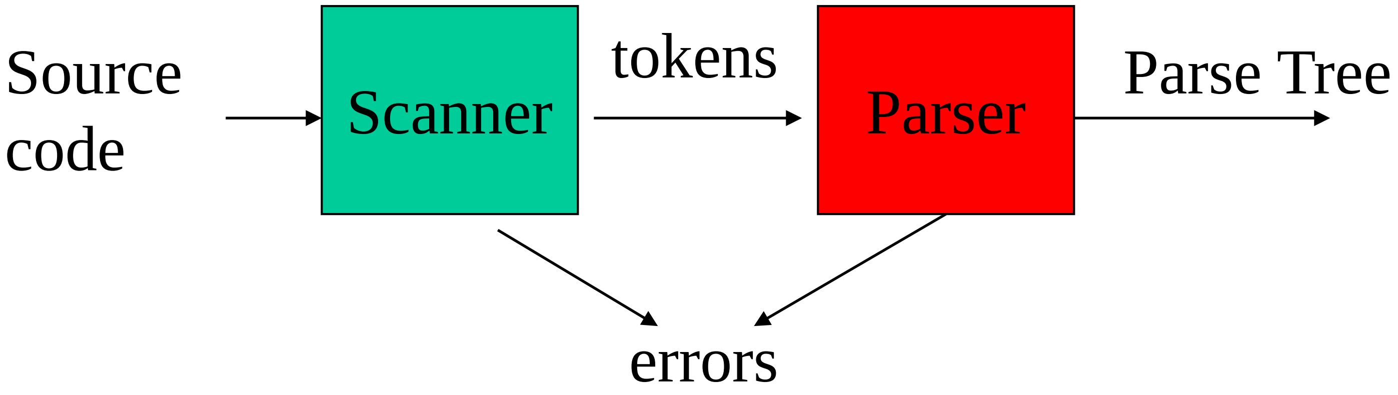
Front-End (Cont.)



Scanner:

- Maps characters into tokens – the basic unit of syntax
    - x = x + y becomes <id, x> <=, > <id, x> <+, > <id, y>
- Eliminate white space (tabs, blanks, comments)

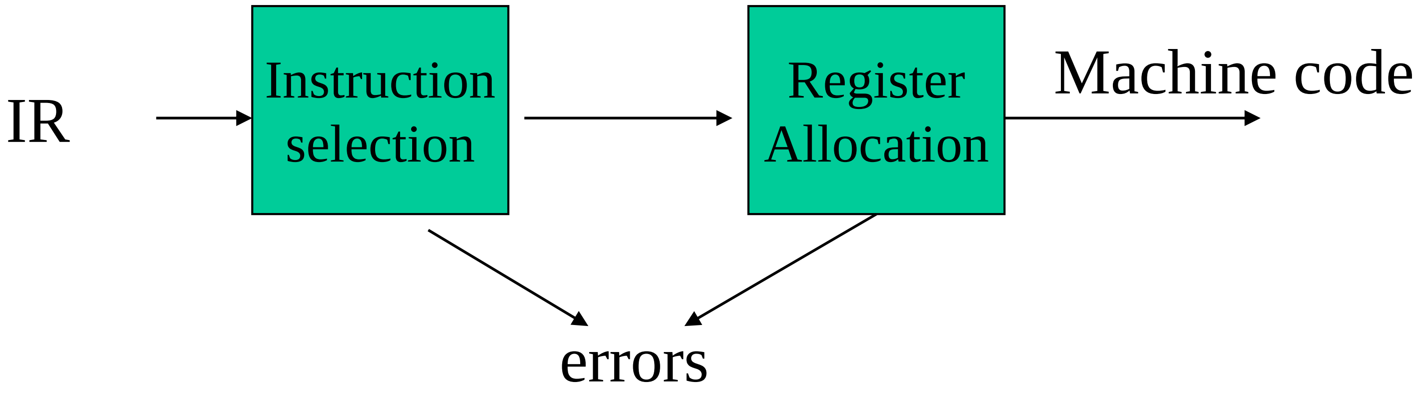
Front-End (Cont.)



Parser:

- Recognize context-free syntax
- Guide context-sensitive analysis
- Produce meaningful error messages

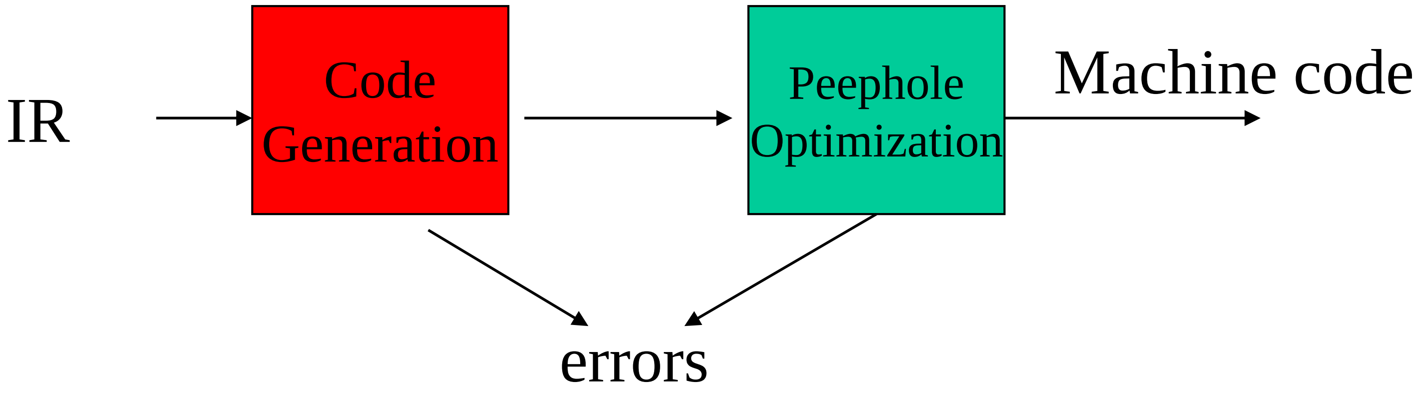
Back-End



Back-End:

- Translate IR into machine code
- Choose instructions for each IR operation
- Decide what to keep in registers at each point

Two Main Components of Back-End



IR

Code Generation

Peephole Optimization

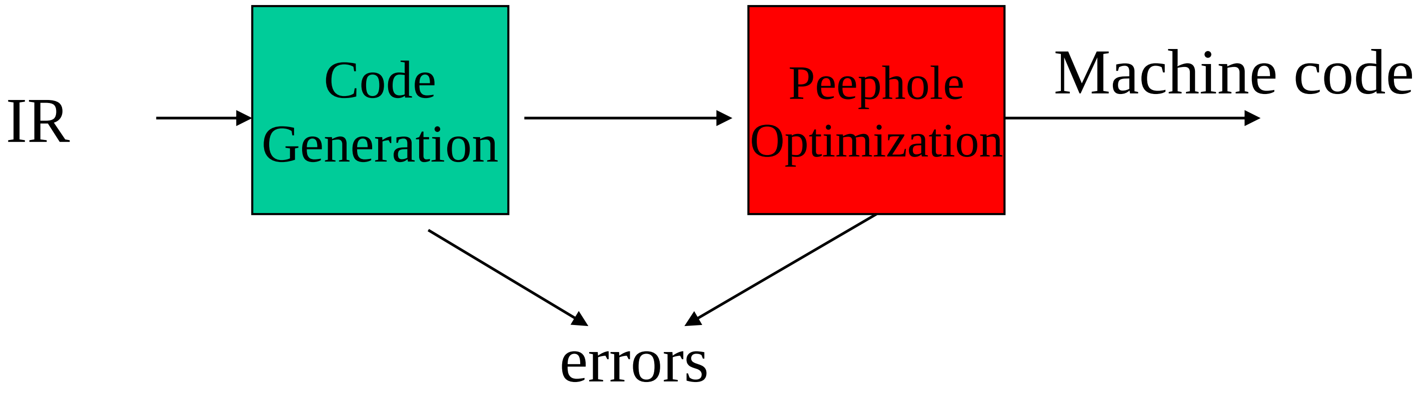
Machine code

errors

Code Generator:

- Produce compact fast code
- Use available addressing modes

Back-End (Cont.)



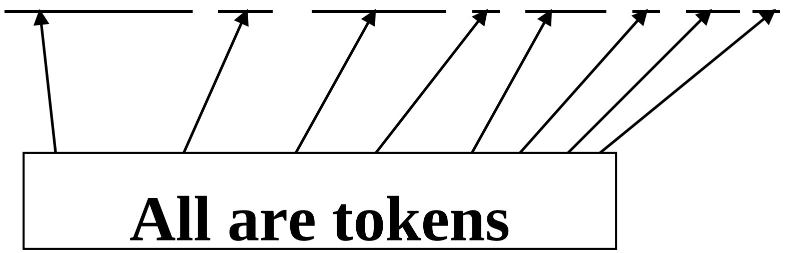
Peephole Optimization:

- Limited resources
- Optimal allocation is difficult

Phase 1. Lexical Analysis

Easiest Analysis - Identify <u>tokens</u> which are the basic building blocks

For Example: Position := initial + rate * 60 ;

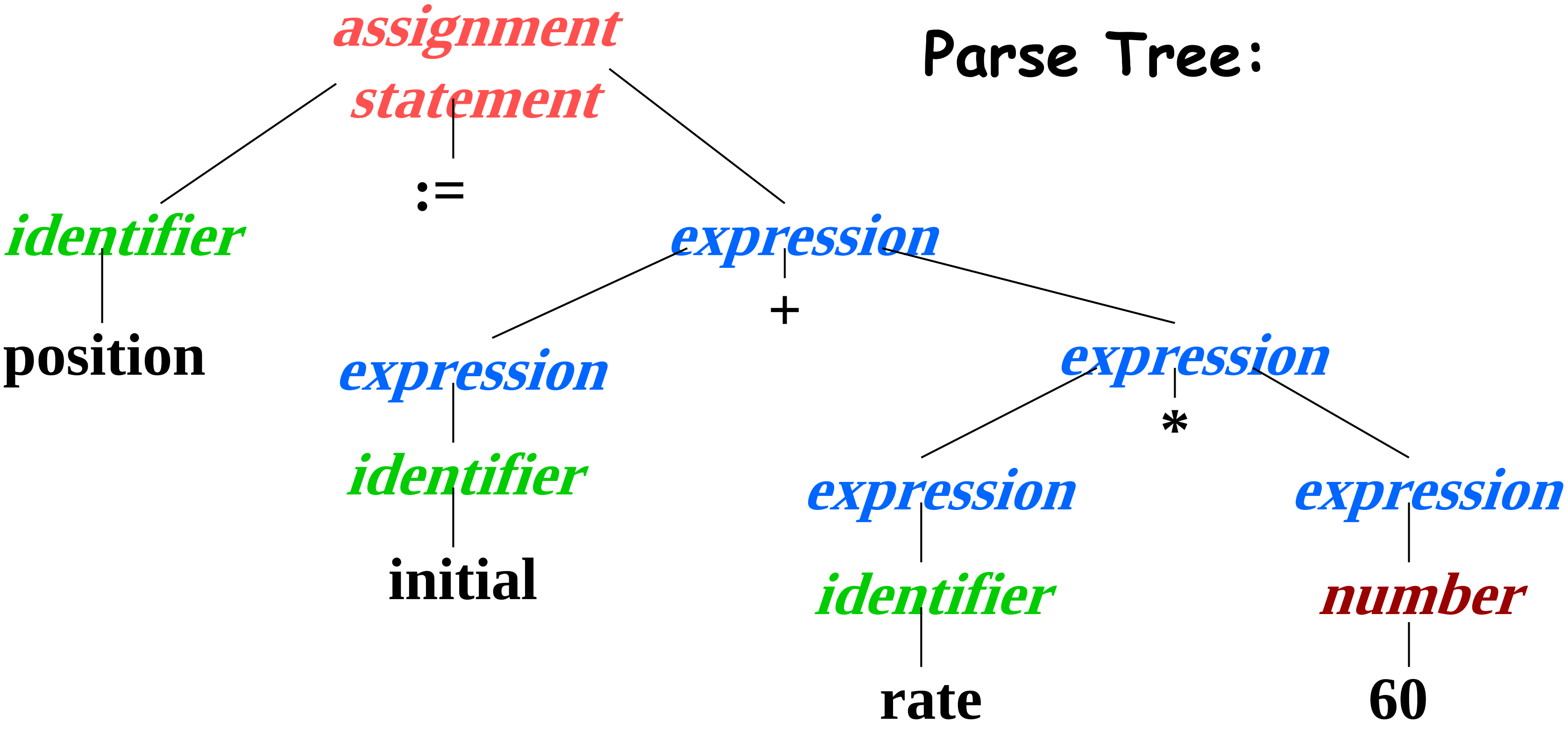


All are tokens

Blanks, Line breaks, etc. are scanned out

Phase 2. Syntax Analysis or Parsing

Parse Tree:



assignment statement

identifier

:=

expression

position

expression

+

expression

identifier

*

initial

expression

expression

identifier

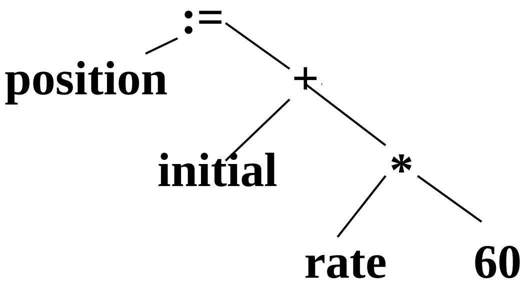
number

rate

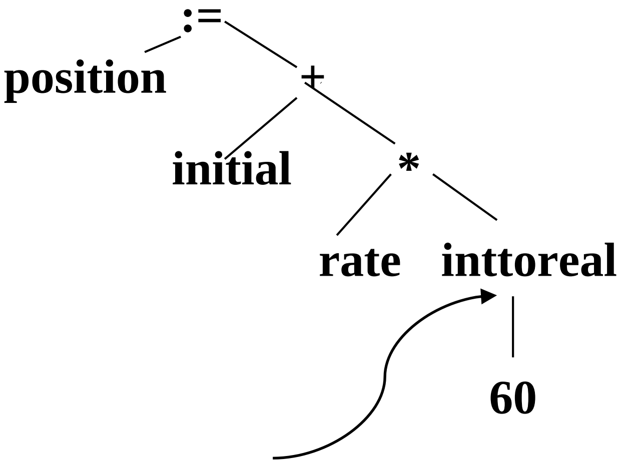
60

Nodes of tree are constructed using a Grammar for the source language

- Finds Semantic Errors



Syntax Tree



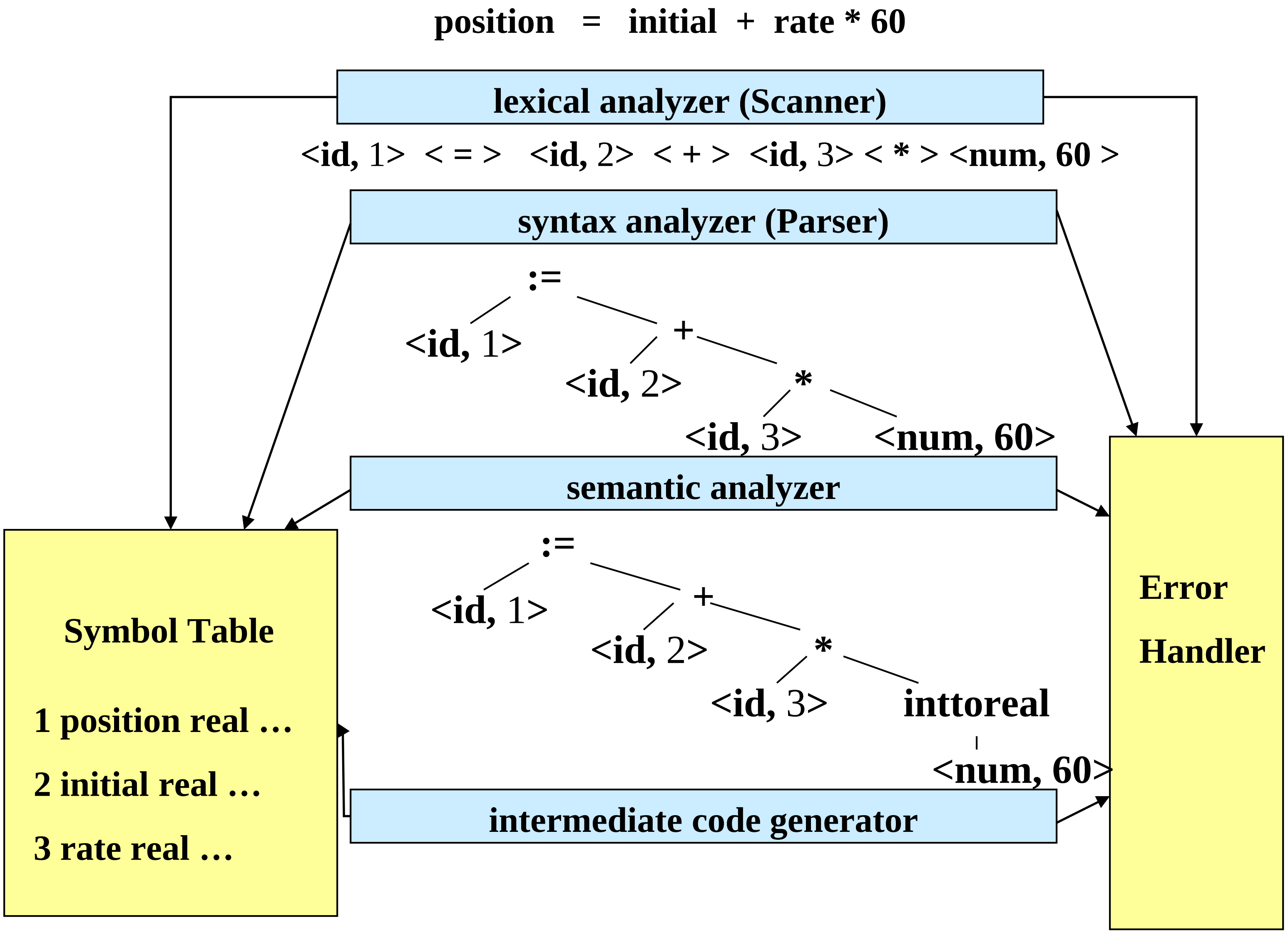
Conversion Action

- One of the Most Important Activities in This Phase:
- Type Checking - Legality of Operands

Supporting Phases

- Symbol table creation / maintenance
  - Contains info (address, type, scope, args) on certain Tokens, typically identifiers
  - Data structure created/initialized during lexical analysis; and updated during later analysis & synthesis
- Error handling
  - Detection of different errors which correspond to all phases; and deciding what happens when an error is found

An example of the Entire Process



position = initial + rate * 60

lexical analyzer (Scanner)

<id, 1> **< = > <id,** 2> **< + > <id,** 3> **< * > <num, 60 >**

syntax analyzer (Parser)

:=
<id, 1>
+
<id, 2>
*****
<id, 3>
<num, 60>

semantic analyzer

:=
<id, 1>
+
<id, 2>
*****
<id, 3>
inttoreal
<num, 60>

intermediate code generator

Symbol Table

1 position real …

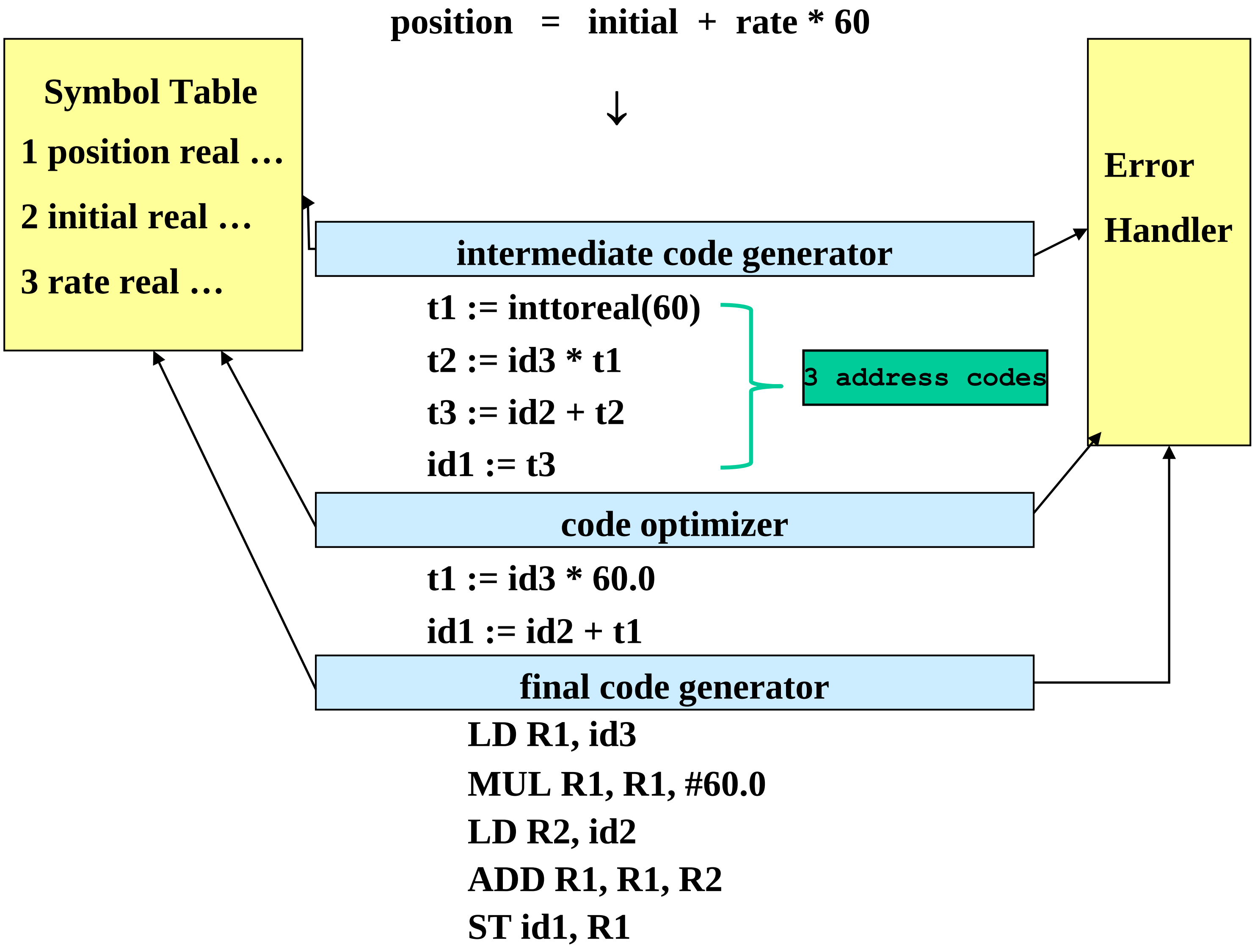
2 initial real …

3 rate real …

Error

Handler

An example of the Entire Process



position = initial + rate * 60

↓

Symbol Table

1 position real …

2 initial real …

3 rate real …

Error

Handler

intermediate code generator

t1 := inttoreal(60)
t2 := id3 * t1
t3 := id2 + t2
id1 := t3

`3 address codes`

code optimizer

t1 := id3 * 60.0
id1 := id2 + t1

final code generator

LD R1, id3
MUL R1, R1, #60.0
LD R2, id2
ADD R1, R1, R2
ST id1, R1