# Compiler Techniques

## 1. Introduction

Huang Shell Ying

The future belongs to those with the underlying ability to learn and the underlying passion for knowledge.

Warren Fernandez
Editor, Straits Times.
15 November, 2015.

# Teaching staff members

- Huang Shell Ying (assyhuang@ntu.edu.sg),
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  - Tutorials and Labs

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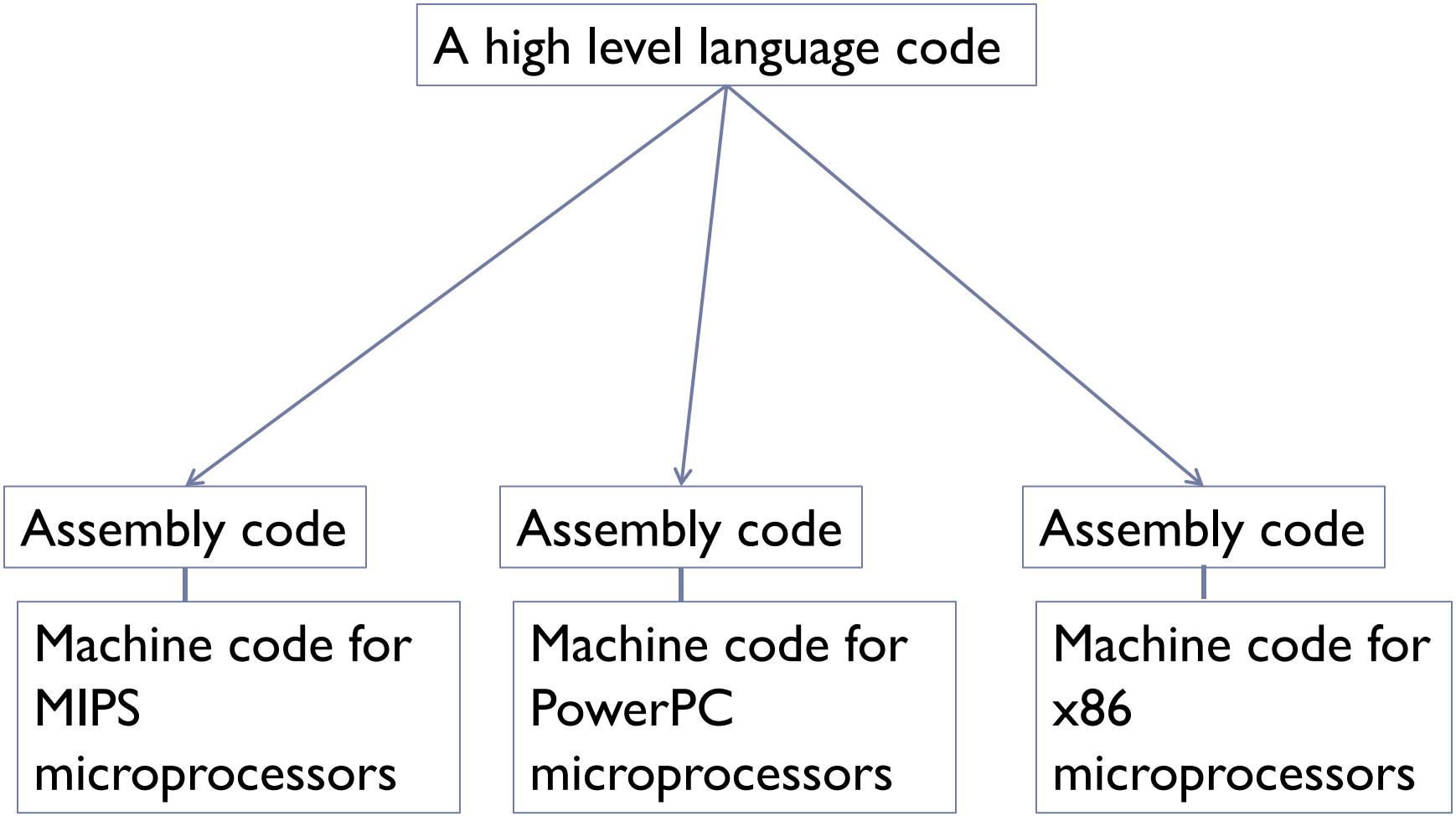
  - Tutorials

# Programming Languages

- A programming language is a formal constructed language designed to communicate instructions to a machine, particularly a computer (quote Wikipedia).
- Machine code or machine language is a set of instructions executed directly by a computer's central processing unit (CPU).
  - Every processor or processor family has its own machine code instruction set.
- An assembler language is a low level programming language, generally with a one-to-one correspondence with the machine code of a processor family.
- A high level programming language is human-readable and needs compiling or interpreting.

# Programming Languages



# A Compiler is a Translator

- Programs in a high level programming language may be translated by a compiler ( and an assembler) to machine code programs.

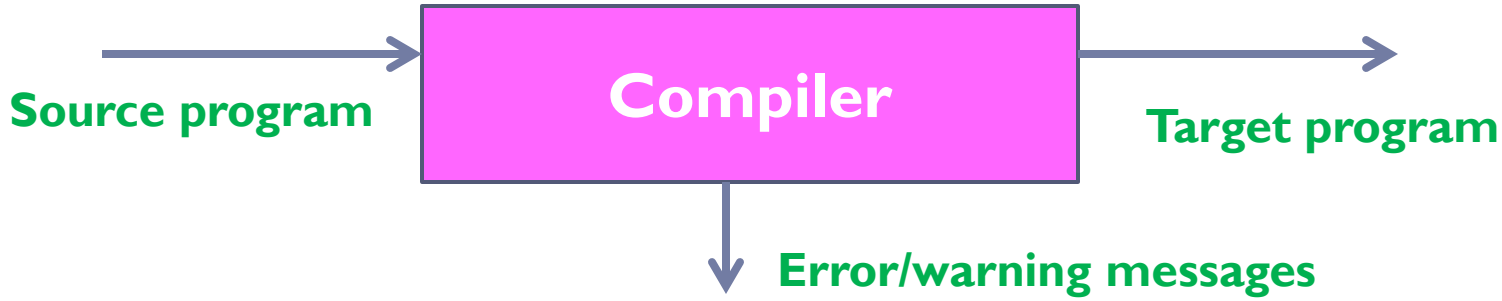
```
scanf("%f%f%f", &a, &b, &c);
d = b*b – 4*a*c;
If  (d==0)  {
    root1 = -b /(2* a);
    printf("Root is: %.3f ", root1);
} else  {
    ….
}
```

```
load  b
dup
mul
load  4
load  a
mul
load   c
mul
sub
store  d
```

Binary machine code

- A **compiler** is a program that reads a program in one language and translate it into an equivalent program in a low-level language, such as a microprocessor's or a simple virtual machine's language

# A Compiler is a Translator




- If the target program is in a machine code, the target program will be **executed directly** on the machine.


- A target program is not necessarily in a machine code. It can be in a virtual machine's language, e.g. Java bytecode.

# Interpreter

- An **interpreter** directly executes the operations specified in the source program on inputs supplied by the user


  - only applicable if the source program is in a language that has an interpreter on the machine
  - If a program is interpreted, it takes a longer time to run than if it had been compiled
  - Programs may be modified as execution proceeds
  - Interpreters provide a significant degree of machine independence – no machine code is generated, just port the interpreter to a new machine

# Learning Objectives

To give students an understanding of compilers and the techniques involved in programming language translation.

- The major stages of compilation, including lexing, parsing, semantic analysis, optimization and code generation, are described.
- Relevant tools and techniques introduced.

# Learning Outcomes

1. Understand the steps and techniques involved in **programming language translation**.
2. Use **regular expressions** and **context free grammars** to describe languages, and to employ open-source tools to create **recognisers** for them
3. Understand the concept of **abstract syntax trees** and how they are used as the basis for **name binding analysis** and **type checking**.
4. Understand how a compiler generates **machine code**, and how to use simple **data flow analysis** techniques for **optimization**.
5. Apply ideas, techniques, and skills learnt to general software design.

# Why Study Compiler Techniques

- Programming language design and compiler construction are still evolving and are active areas of research and development.
- To be a good **user** or designer of programming languages, one must know
  - how a computer carries out the instructions of a program (including how data are represented)
  - the techniques by which a high-level program is converted into something that runs on an actual computer.
- Many techniques used in compilers are useful in (i) general software design and software development; (ii) mobile and industry applications.

DesignScript

# Course Schedule

| Week | Lecture Topic | Tutorial (hour (topic)) | Lab |
|---|---|---|---|
| 1 | Introduction to compilers & Lexical Analysis | | |
| 2 | Lexical Analysis | | |
| 3 | Parsing | 1 (Lexical Analysis) | |
| 4 | Parsing | 0.5(Lexical Analysis)+ 0.5 (Parsing) | lab 1(Lexical Analysis) |
| 5 | Parsing & Semantic Analysis | 1 (Parsing) | |
| 6 | Semantic Analysis | 1 (Parsing) | lab 2(Parsing) |
| 7 | Semantic Analysis | 1 (Semantic Analysis) | |
| | | | |
| 8 | Code Generation | 1 (Semantic Analysis) | lab 3(Semantic Analysis) |
| 9 | Code Generation | 1 (Semantic Analysis) | |
| 10 | Code Generation | 1 (Code Generation) | Quiz (90 minutes) |
| 11 | Code Generation | 1 (Code Generation) | |
| 12 | Optimization | 1 (Code Generation) | lab 4(Code Generation) |
| 13 | Optimization | 1 (Optimization) | |

# Grading Information

Attendance is important

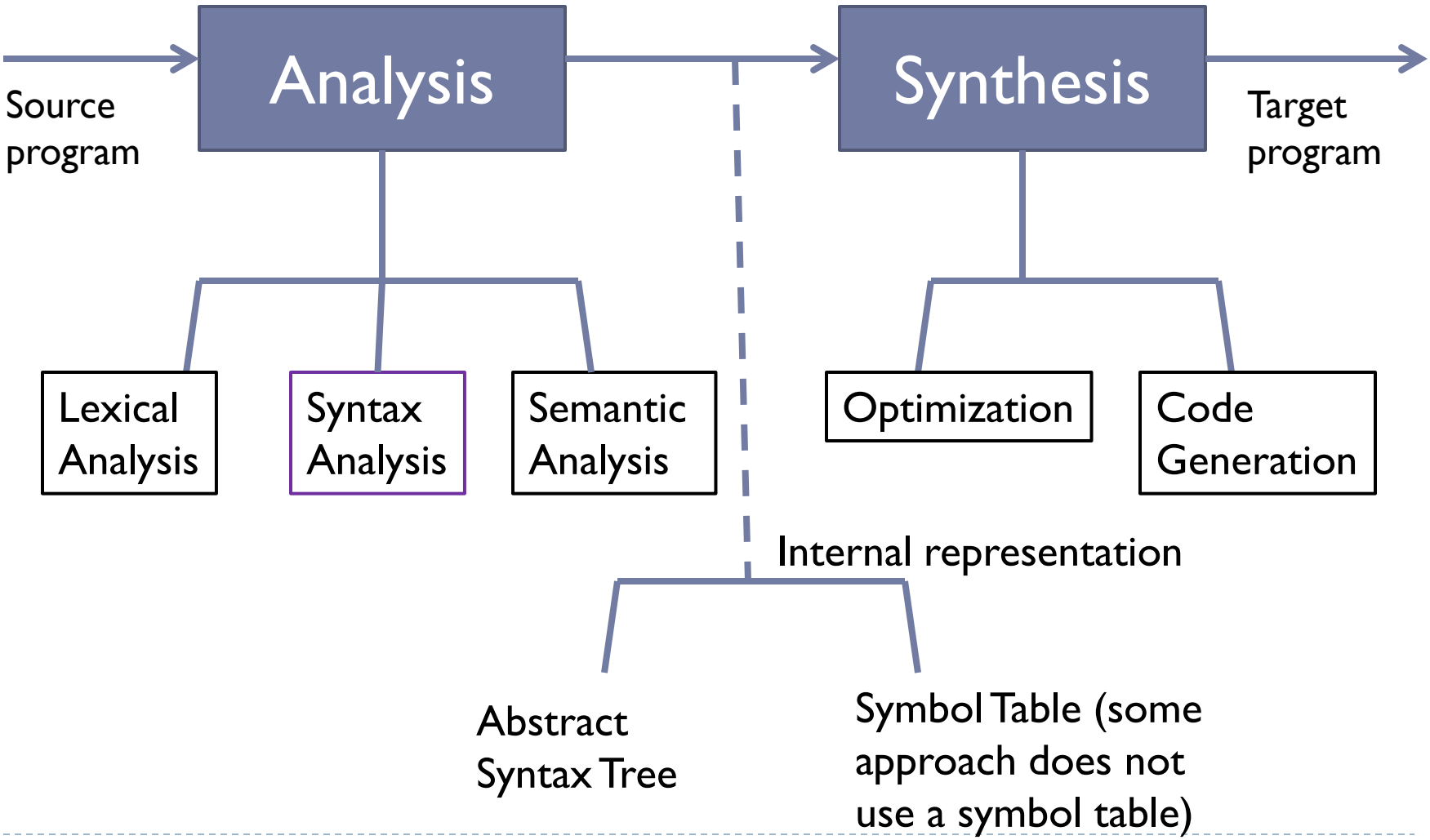
- 3 students working in one team for lab assignments
- Same grade for everyone in the same team, in general
- 3 lab submissions - 21% of the final grade
- Attendance in Lab session 3 - 3% of the final grade
- One quiz in Week 10/11 (compulsory) - 16% of the final grade
- Final exam – 60% of the final grade
- If one attends tutorials regularly and asks questions such that your tutor/lecturer remembers you – marks added to the quiz results to improve grades (up to B-)

# General Information

Slide 24

- Main references:
  - Crafting a Compiler, by C. N. Fischer, R. K. Cytron, R. J. LeBlanc, Pearson, 2010, ISBN-13: 978-0-13-801785-9
  - Compilers: Principles, Techniques & Tools, 2nd Ed, by A. Aho, M. S. Lam, R. Sethi, J. D. Ullman, Pearson, 2006, ISBN-13: 978-1-292-02434-9.
- Other reference:
  - Modern Compiler Implementation in Java, 2nd Ed, by A. Appel, J. Palsberg, Cambridge University Press, 2004, ISBN 0-521-82060-X.

# The Structure of a Compiler



# Lexical Analysis

- The first step: recognize words.
  - Smallest unit above letters

```
This book is the main reference.
```

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

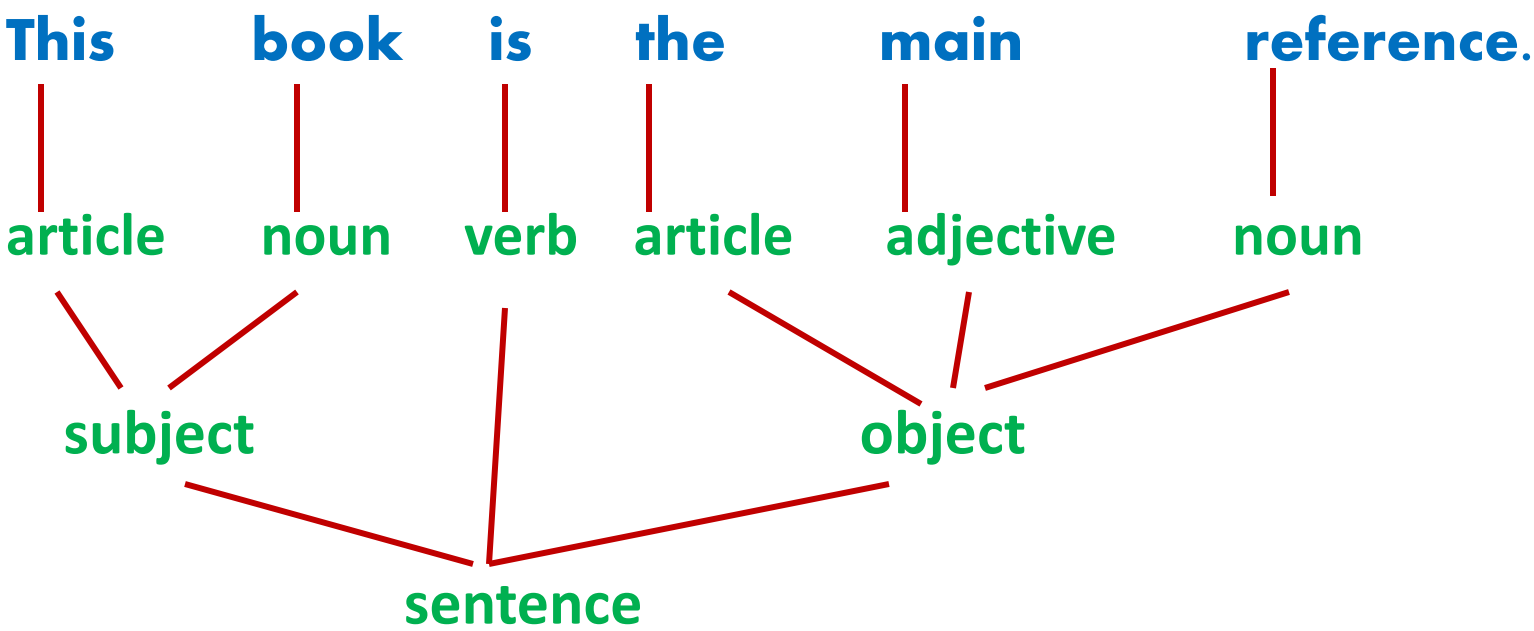
```
If x == y then z = 1; else z = 2;
```

- Tokens:

```
IF id EQ id THEN id ASSIGN intliteral …
```

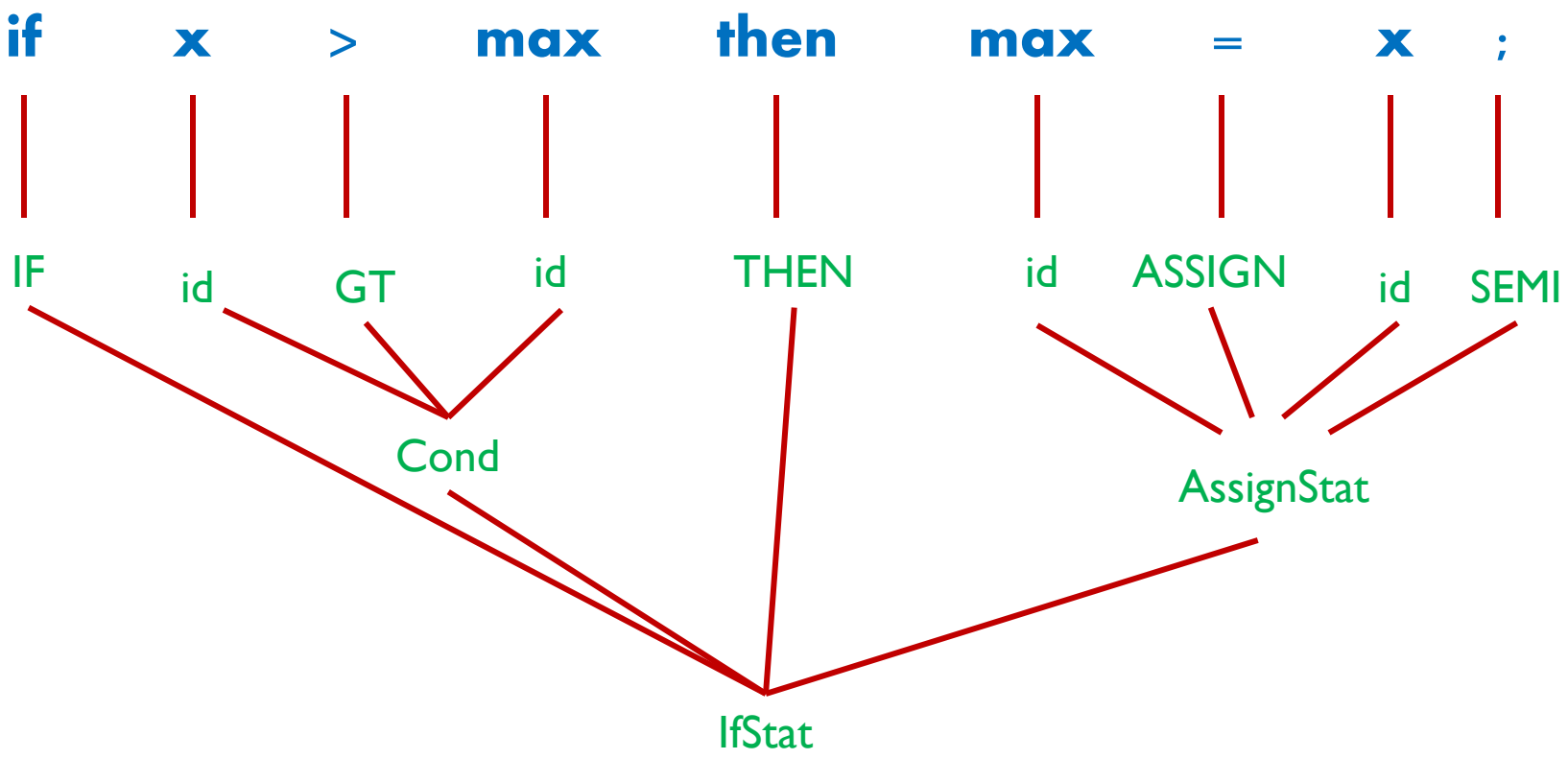
# Syntax Analysis

- Once words are understood, the next step is to understand sentence structure (and catch syntax errors)
- Syntax analysis (Parsing) = Diagramming Sentences
  - The diagram is a tree



# Syntax Analysis

- Parsing a program is the same



# Semantic Analysis

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

- Compilers perform limited analysis to catch inconsistencies

For example, can you detect what are wrong below?

```
{     int a = 0;
      float a = -0.5;
      cout << a;
      b = a;
      a = "hello";
}
```

# Optimization

- No strong counterpart in English, but akin to editing
- Automatically modify programs so that they
  - Run faster
  - Use less memory
  - In general, conserve some resources

For example,

```
t = z * 2;
if (t > y)  {
        z = z * 2;
        ......   }
```

# Code Generation

- Produces assembly code (usually)
- A translation into another language
  - Analogous to human translation

For example,

Y = X*10.0; →

```
LDF   R2, X
MUL   R2, #10.0
STF   Y, R2
```

# Some Review Questions/tasks

1. ‘google’ the term ‘machine code’.
2. ‘google’ the term ‘assembly language’.
3. What does a compiler do?
4. What does an interpreter do?
5. What is the structure of a compiler and what are the main tasks involved?

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A hand crafted parser for DesignScript that will perform better than the current auto-generated parser is desired. …

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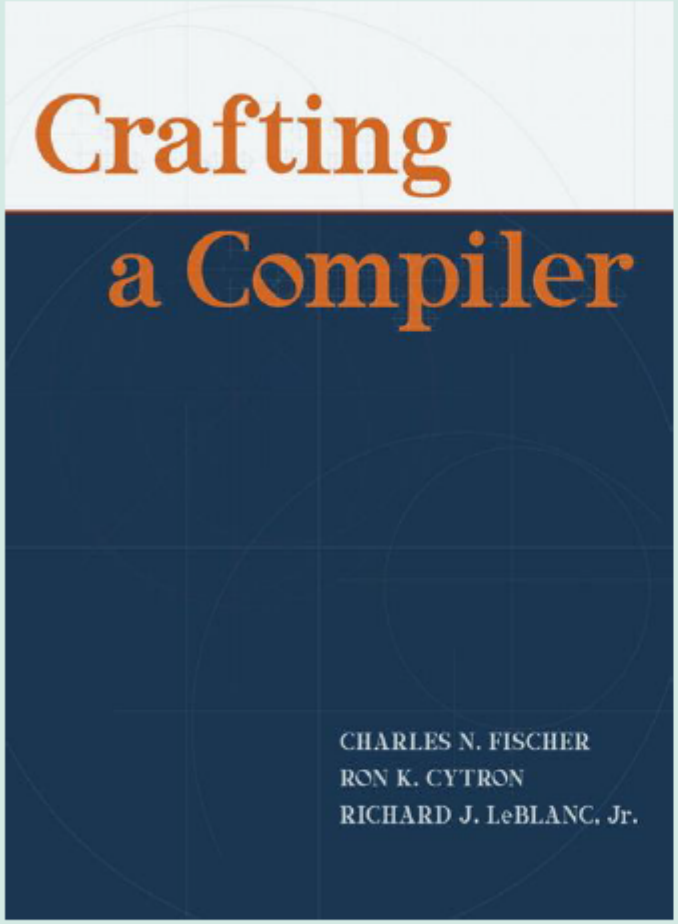


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