CS412/413

Introduction to
Compilers and Translators

Lecture 1: Overview

21 Jan 08

Outline

- Course Organization
  - General course information
  - Homework & project information

- Introduction to Compilers
  - What are they?
  - Why do we need them?
  - What is their general structure?

General Information

When Where	MWF 10:10 - 11:00AM Phillips 213
Instructor Teaching Assistant	Tim Teitelbaum TBD
Course staff email	cs412-l@cs.cornell.edu
Web page	courses.cs.cornell.edu/cs412
Newsgroup	cornell.class.412

Important

- CS 413 is required!
- Large implementation project
- Substantial amount of theory

Textbooks

- Optional texts
  - Compilers -- Principles, Techniques and Tools (Dragon Book), by Aho, Sethi and Ullman (1986)
  - Modern Compiler Implementation in Java, by Andrew Appel (2002)
  - Engineering a Compiler, by Linda Torczon and Keith Cooper (2003)
- They will be on reserve in Engineering Library

Work Distribution

- Theory:
  - Homeworks = 20%
    - 4 homeworks: 5% each
  - Exams = 35%
    - 2 prelims: 17% and 18%; no final exam
- Practice:
  - Programming Assignments = 45%
    - 6 assignments: 5/9/9/9/9
    - Project demo

Homeworks

- 4 homework assignments
  - Three assignments in first half of course
  - One homework in second half
- Not done in groups
  - do your own work

Project

- Implementation:
  - Designed language = a subset of Java
  - Generated code = assembly x86
  - Implementation language = Java
- 5 programming assignments
- Groups of 3-4 students
  - Usually same grade for all
  - Group information due Friday
  - We will respect consistent preferences

Assignments

- Due at beginning of class
  - Homeworks: paper turn in (at beginning of class)
  - Project files: electronic turn in (day before class)
  - Assignments managed with Course Management System (CMS)

- Late homework, programming assignments increasingly penalized
  - Penalty linearly increasing : 10% per day
  - 1 day: 10%, 2 days: 20%, 3 days: 30%, etc.

Why Take This Course?

- CS412/413 is an elective course

- Reason #1: understand compilers/languages
  - Understand code structure
  - Understand language semantics
  - Understand relation between source code and generated machine code
  - Become a better programmer

Why Take This Course? (ctd.)

- Reason #2: nice balance of theory and practice:
  - Theory:
    - Lots of mathematical models: regular expressions, automata, grammars, graphs, lattices
    - Lots of algorithms that use these models
  - Practice:
    - Apply theoretical notions to build a real compiler
    - Better understand why “theory and practice are the same in theory, but different in practice”

Why Take This Course? (ctd.)

- Reason #3: Programming experience
  - Write a large program that manipulates complex data structures
  - Learn how to be a better programmer in groups
  - Learn more about Java and Intel x86 architecture and assembly language

Why Take This Course? (ctd.)

- Reason #4: Technical background for emerging field of software assurance
  - Software assurance will be major priority of coming decade
  - Bug-finding and security-violation finding tools build on compiler techniques

What Are Compilers?

- Compilers translate *information* from one *representation* to another.
- Most commonly, the information is a *program*
- Typically
  - “Compilers” translate from high-level *source* code to low-level code (e.g., *object* code)
  - “Translators” transform representations at the same level of abstraction

Examples

- Typical compilers: gcc, javac
- Non-typical compilers:
  - latex (document compiler) :
    - Transforms a LaTeX document into DVI printing commands
    - Input information: document (not program)
  - C-to-Hardware compiler:
    - Generates hardware circuits for C programs
    - Output is lower-level than typical compilers
- Translators:
  - f2c : Fortran-to-C translator (both high-level)
  - latex2html : LaTeX-to-HTML (both documents)
  - dvi2ps: DVI-to-PostScript (both low-level)

In This Class

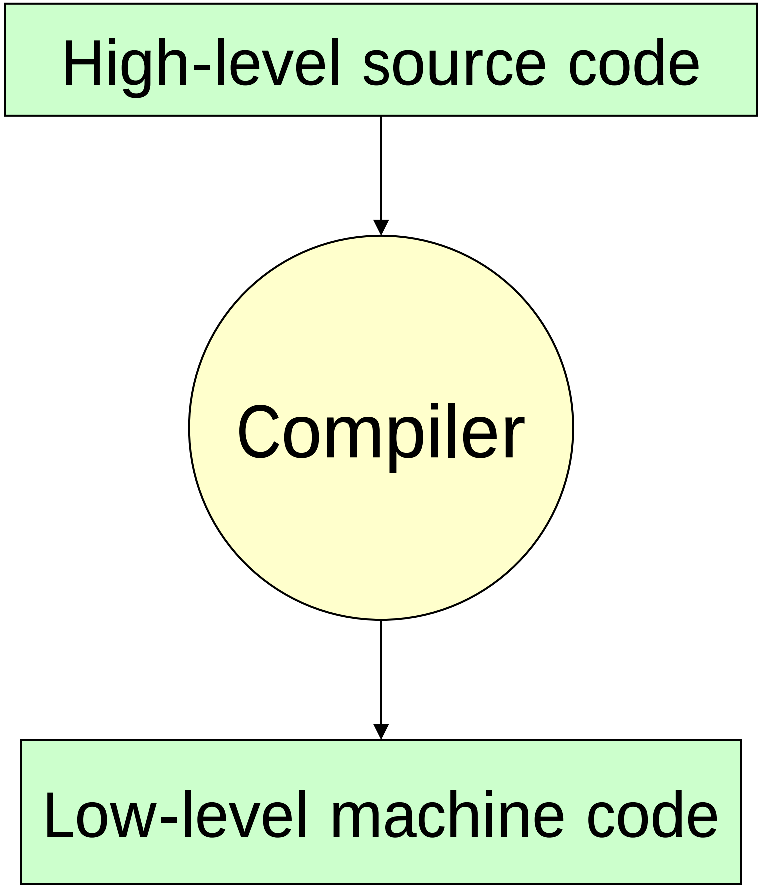
- We will study typical compilation: from programs written in high-level languages to low-level object code and machine code

- Most of the principles and techniques in this course apply to non-typical compilers and translators

Why Do We Need Compilers?

- It is difficult to write, debug, maintain, and understand programs written in assembly language
- Tremendous increase in productivity when first compilers appeared (about 55 years ago)
- There are still few cases when it is better to manually write assembly code
  - E.g., to access low-level resources of the machine (device drivers)
  - These code fragments are very small; the compiler handles the rest of the code in the application

Overall Compiler Structure



Source Code

- Optimized for human readability
  - Matches human notions of grammar
  - Uses named constructs such as variables and procedures

```
int expr(int n)
{
    int d;
    d = 4 * n * n * (n + 1) * (n + 1);
    return d;
}
```

Assembly and Machine Code

- Optimized for hardware
  - Consists of machine instructions; uses registers and unnamed memory locations
  - Much harder to understand by humans

```
lda $30,-32($30)
stq $26,0($30)
stq $15,8($30)
bis $30,$30,$15
bis $16,$16,$1
stl $1,16($15)
lds $f1,16($15)
sts $f1,24($15)
ldl $5,24($15)
bis $5,$5,$2
s4addq $2,0,$3
ldl $4,16($15)
mull $4,$3,$2
ldl $3,16($15)
        addq $3,1,$4
        mull $2,$4,$2
        ldl $3,16($15)
        addq $3,1,$4
        mull $2,$4,$2
        stl $2,20($15)
        ldl $0,20($15)
        br $31,$33
$33:
        bis $15,$15,$30
        ldq $26,0($30)
        ldq $15,8($30)
        addq $30,32,$30
        ret $31,($26),1
```

Translation Efficiency

- Goal: generate machine code that describes the same computation as the source code

- Is there a unique translation?

- Is there an algorithm for an "ideal translation"? (ideal = either fastest or smallest generated code)

- Compiler optimizations = find *better* translations!

Example: Output Assembly Code

Unoptimized Code

```
    lda $30,-32($30)
    stq $26,0($30)
    stq $15,8($30)
    bis $30,$30,$15
    bis $16,$16,$1
    stl $1,16($15)
    lds $f1,16($15)
    sts $f1,24($15)
    ldl $5,24($15)
    bis $5,$5,$2
    s4addq $2,0,$3
    ldl $4,16($15)
    mull $4,$3,$2
    ldl $3,16($15)
    addq $3,1,$4
    mull $2,$4,$2
    ldl $3,16($15)
    addq $3,1,$4
    mull $2,$4,$2
    stl $2,20($15)
    ldl $0,20($15)
    br $31,$33
$33:
    bis $15,$15,$30
    ldq $26,0($30)
    ldq $15,8($30)
    addq $30,32,$30
    ret $31,($26),1
```

Optimized Code

```
s4addq $16,0,$0

mull $16,$0,$0
addq $16,1,$16
mull $0,$16,$0
mull $0,$16,$0
ret $31,($26),1
```

Translation Correctness

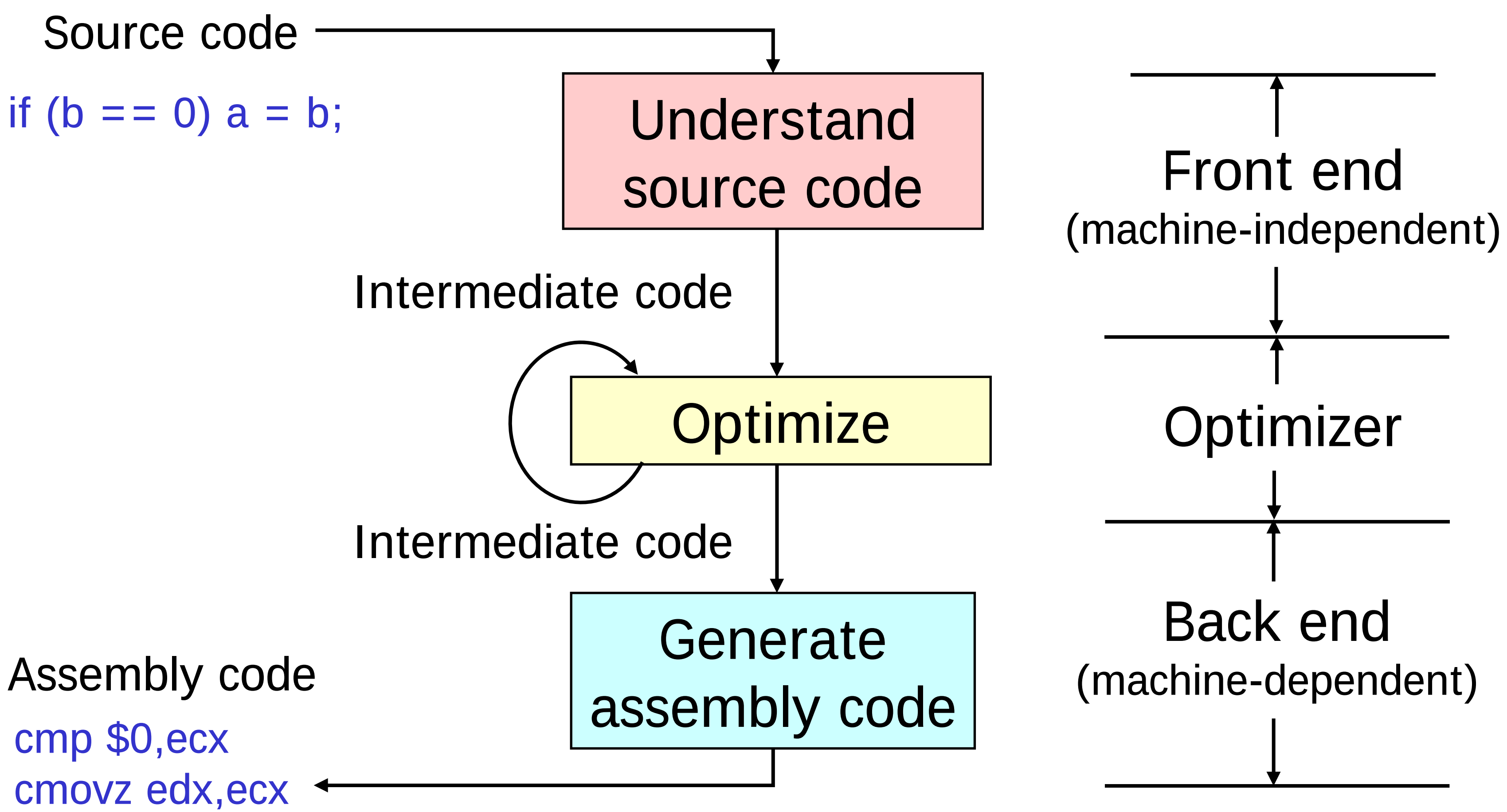
- The generated code must execute precisely the same computation as in the source code

- Correctness is very important!
  - hard to debug programs with broken compiler...
  - implications for development cost, security
  - this course: techniques known to ensure correct translation

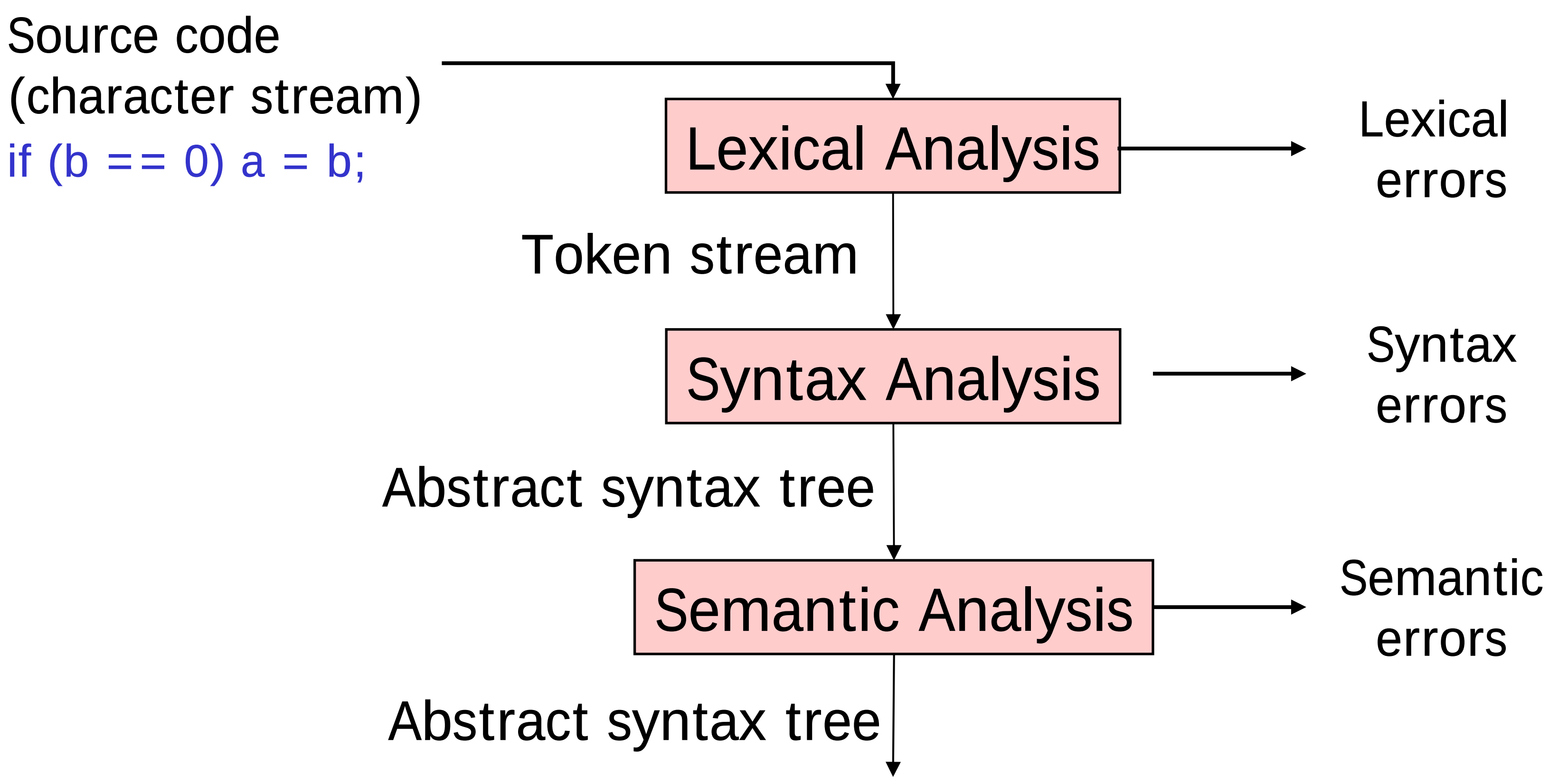
How To Translate?

- Translation is a complex process
  - source language and generated code are very different
- Need to structure the translation
  - Define intermediate steps
  - At each step use a specific program representation
  - More machine-specific, less language-specific as translation proceeds

Simplified Compiler Structure



Simplified Front-End Structure



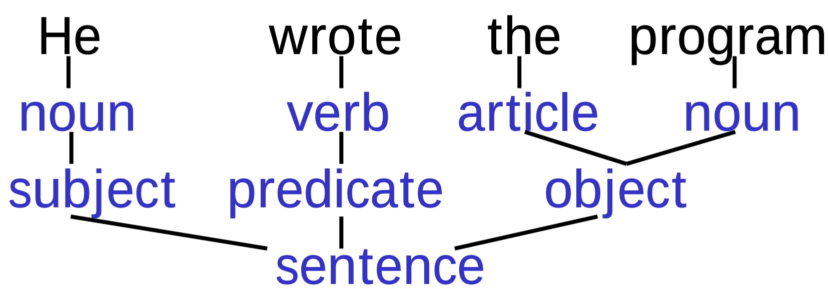
Analogy

- Front end can be explained by analogy to the way humans understand natural languages

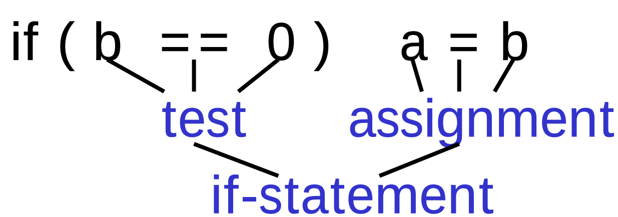
- Lexical analysis
  - Natural language: "He wrote the program"
    words: "he" "wrote" "the" "program"
  - Programming language "if (b == 0) a = b"
    tokens: "if" "(" "b" "==" "0" ")" "a" "=" "b"

Analogy (ctd)

- Syntactic analysis
  - Natural language:



  - Programming language



Analogy (ctd)

- Semantic analysis
  - Natural language:

    He wrote the computer
    noun verb article noun

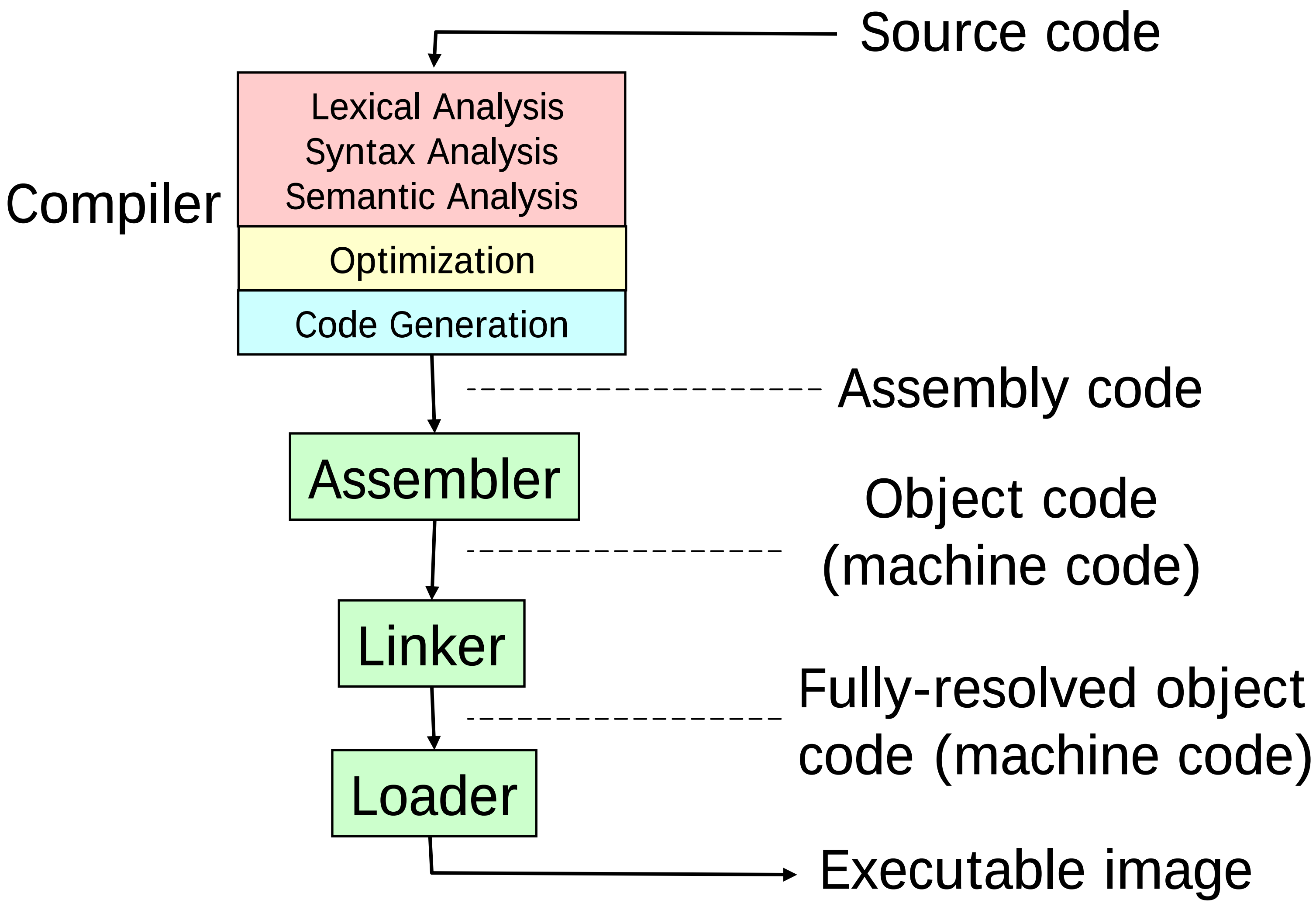
    Syntax is correct; semantics is wrong!

  - Programming language

    if (b == 0) a = foo
    test assignment

    if a is an integer variable and foo is a procedure, then the semantic analysis will report an error

Big Picture


Source code
Compiler
Lexical Analysis
Syntax Analysis
Semantic Analysis
Optimization
Code Generation
Assembly code
Assembler
Object code
(machine code)
Linker
Fully-resolved object
code (machine code)
Loader
Executable image

Tentative Schedule

Lexical analysis	3 lectures
Syntax analysis	6 lectures
Semantic analysis	5 lectures
Prelim #1	
Simple code generation	6 lectures
Analysis	8 lectures
Optimizations	3 lectures
Advanced topics	3 lectures
Prelim #2	
Advanced topics	3 lectures