CSCI-GA.2130-001

Compiler Construction

Mohamed Zahran (aka Z)
mzahran@cs.nyu.edu

Who Am I?

- Mohamed Zahran (aka Z)
- Computer architecture/OS/Compilers Interaction
- http://www.mzahran.com
- Office hours: Wednesdays 5:00-7:00pm
- Room: WWH 328
- Course web page: http://cs.nyu.edu/courses/spring12/CSCI-GA.2130-001/index.html/

Formal Goals of This Course

- What exactly is this thing called compiler?
- How does the compiler interact with the hardware and programming languages?
- Different phases of a compiler
- Develop a simple compiler

Informal Goals of This Course

- To get more than an *A*
- To learn compilers and enjoy it
- To use what you have learned in *MANY* different contexts

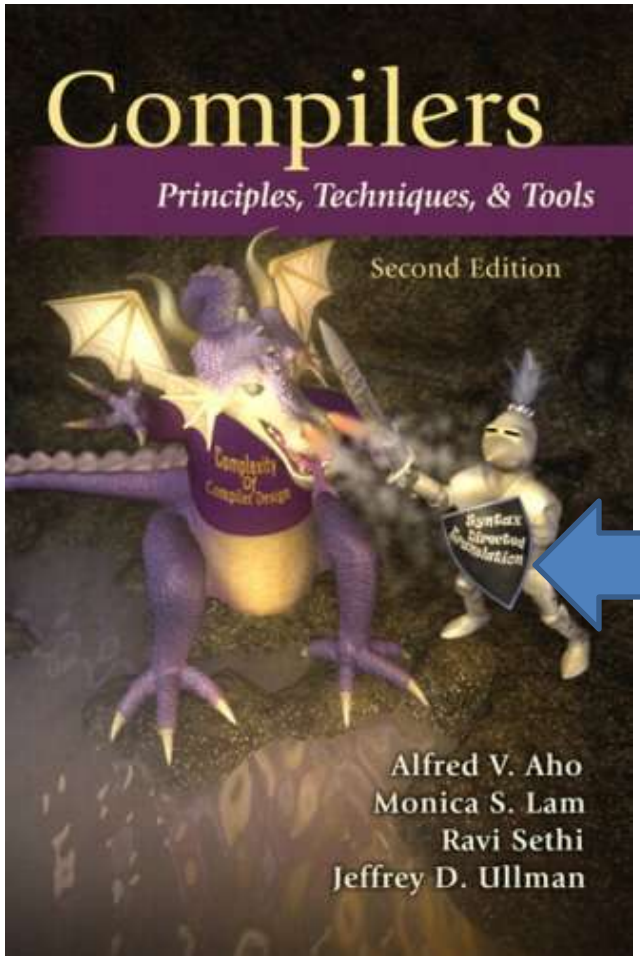
Grading

- **The project (labs): 60%**
  - Due several lectures later
  - Several parts
  - Mostly programming and dealing with tools
  - Can do on your own machine or NYU machines
  - Must be sure that they work on NYU machines
  - Getting help: office hours and mailing list
- **Final exam: 40%**

The Course Web Page

- Lecture slides
- Info about mailing list, labs, … .
- Useful links (manuals, tools, book errata, …).
- Interesting links (geeky stuff!)

The Book

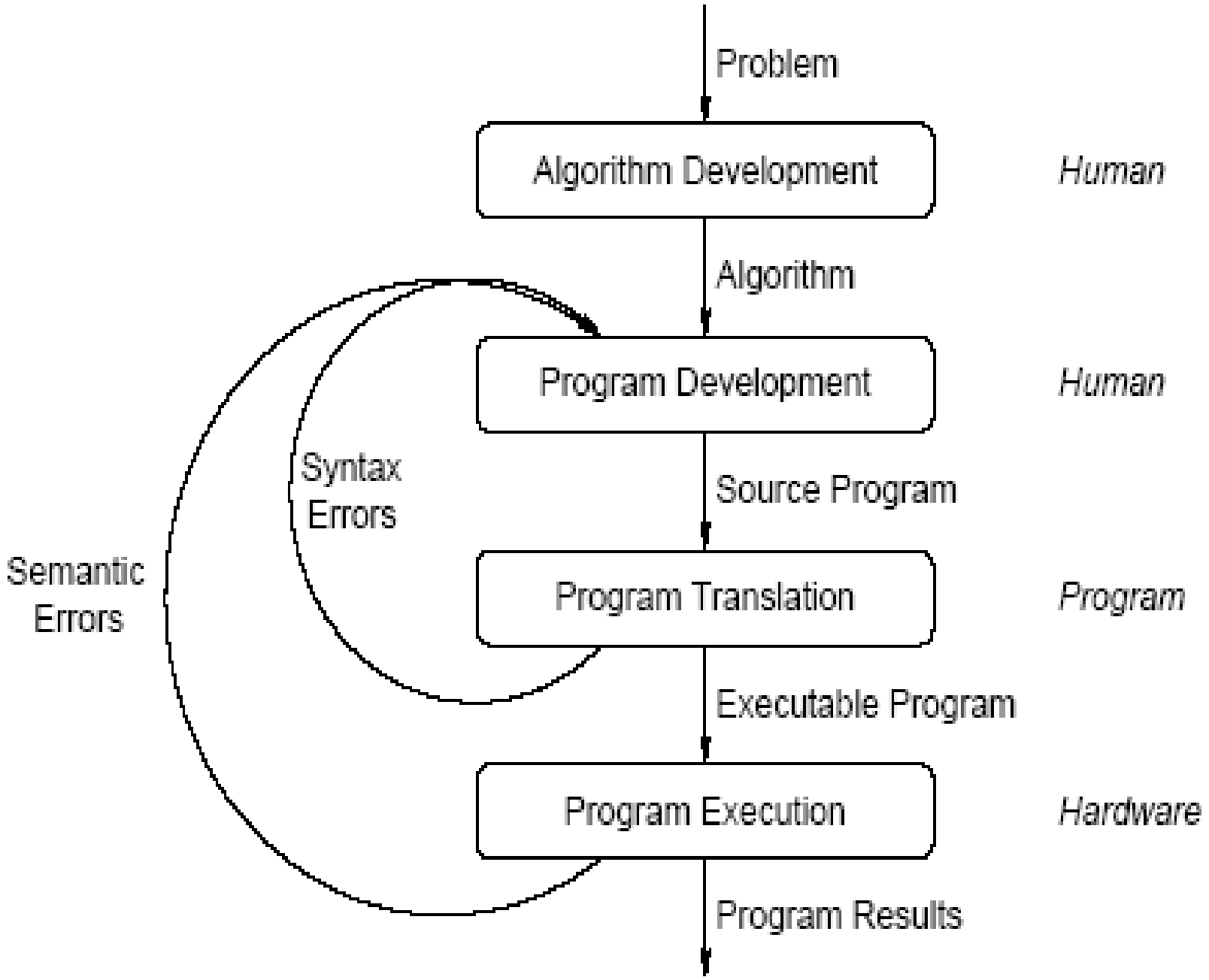


- The classic definitive compiler technology text
- It is known as the **Dragon Book**
- A knight and a dragon in battle, a metaphor for conquering complexity
- We will cover mostly chapters 1 - 8

What Is A Compiler?

- Programming languages are notations for describing computations to people and to machines
- Machines do not understand programming languages
- So a software system is needed to do the translation
- This is the **compiler**

He always liked to open the Annual Programmer's Conference with a joke in binary.

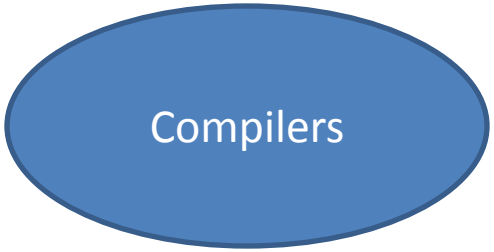

Problem
Algorithm Development
Human
Algorithm
Program Development
Human
Syntax
Errors
Source Program
Semantic
Errors
Program Translation
Program
Executable Program
Program Execution
Hardware
Program Results

Machine Architecture

Compiler writers
must take advantage
of new hardware features

Programming Languages

Compiler writers have to track
new language features



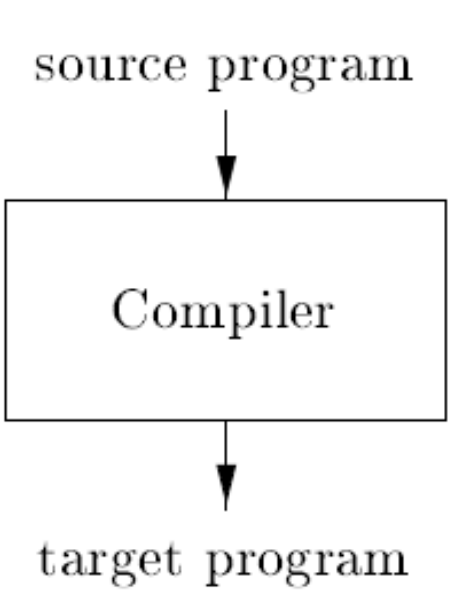
Language Theory

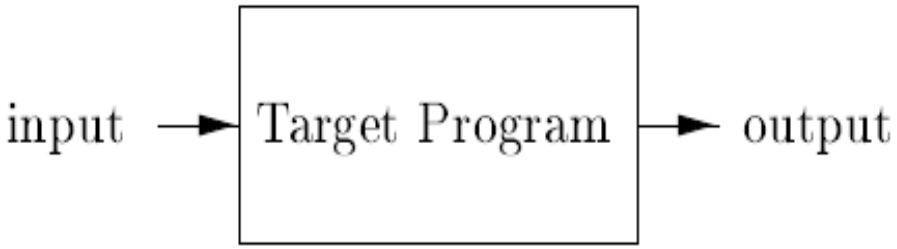
Software Engineering

- Optimizing compilers are hard to build
- Excellent software engineering case study
- Theory meets practice

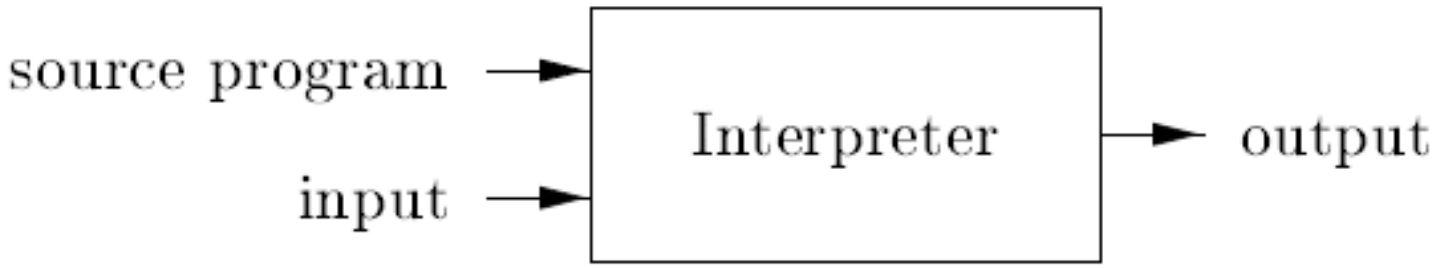
Why Compilers Are So Important?

- Compiler writers have influence over all programs that their compilers compile
- Compiler study trains good developers
- We learn not only how to build compilers but the general methodology of solving complex and open-ended problems
- Compilation technology can be applied in many different areas
  - Binary translation
  - Hardware synthesis
  - DB query interpreters
  - Compiled simulation

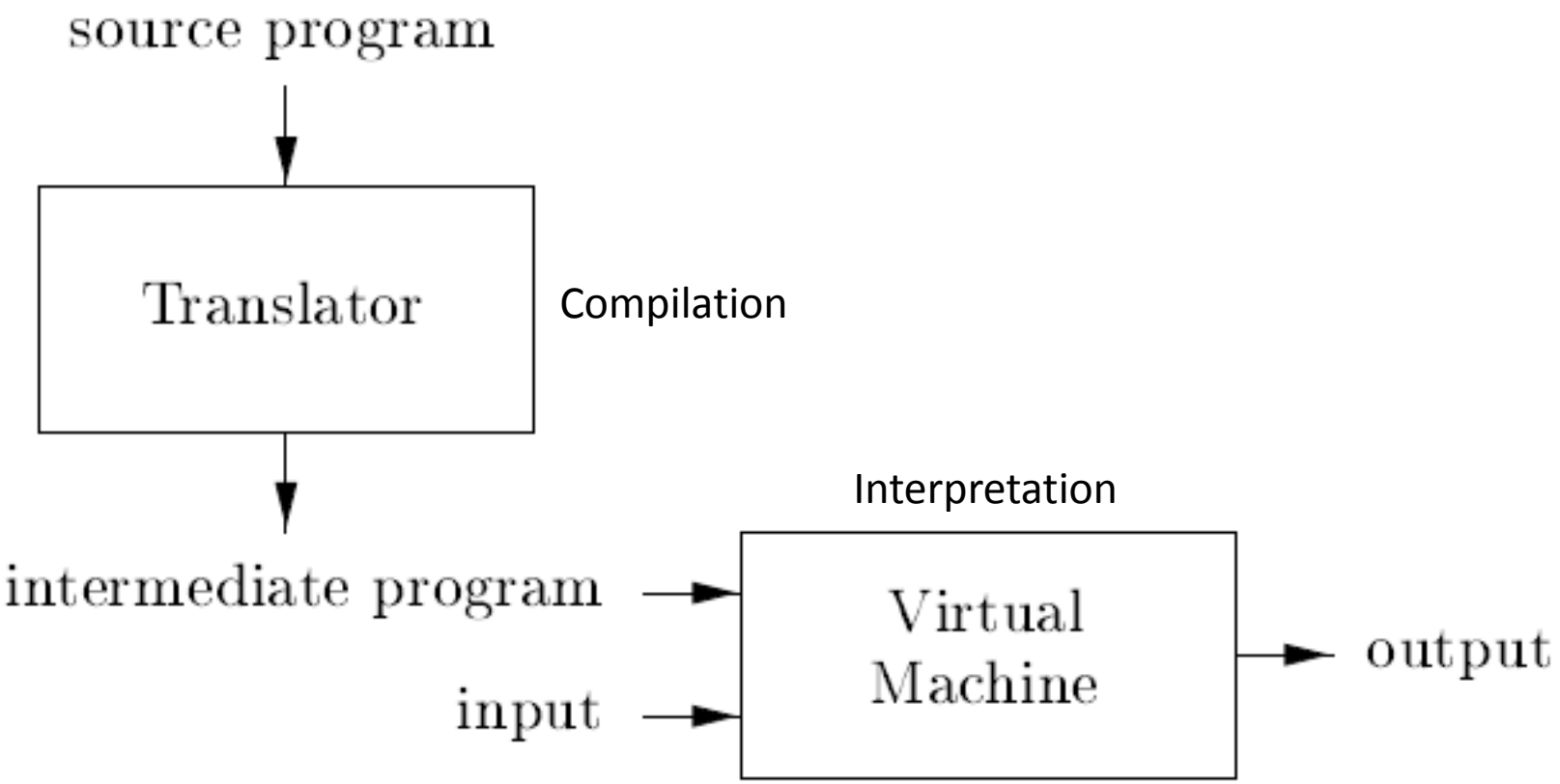

source program
Compiler
target program


input
Target Program
output

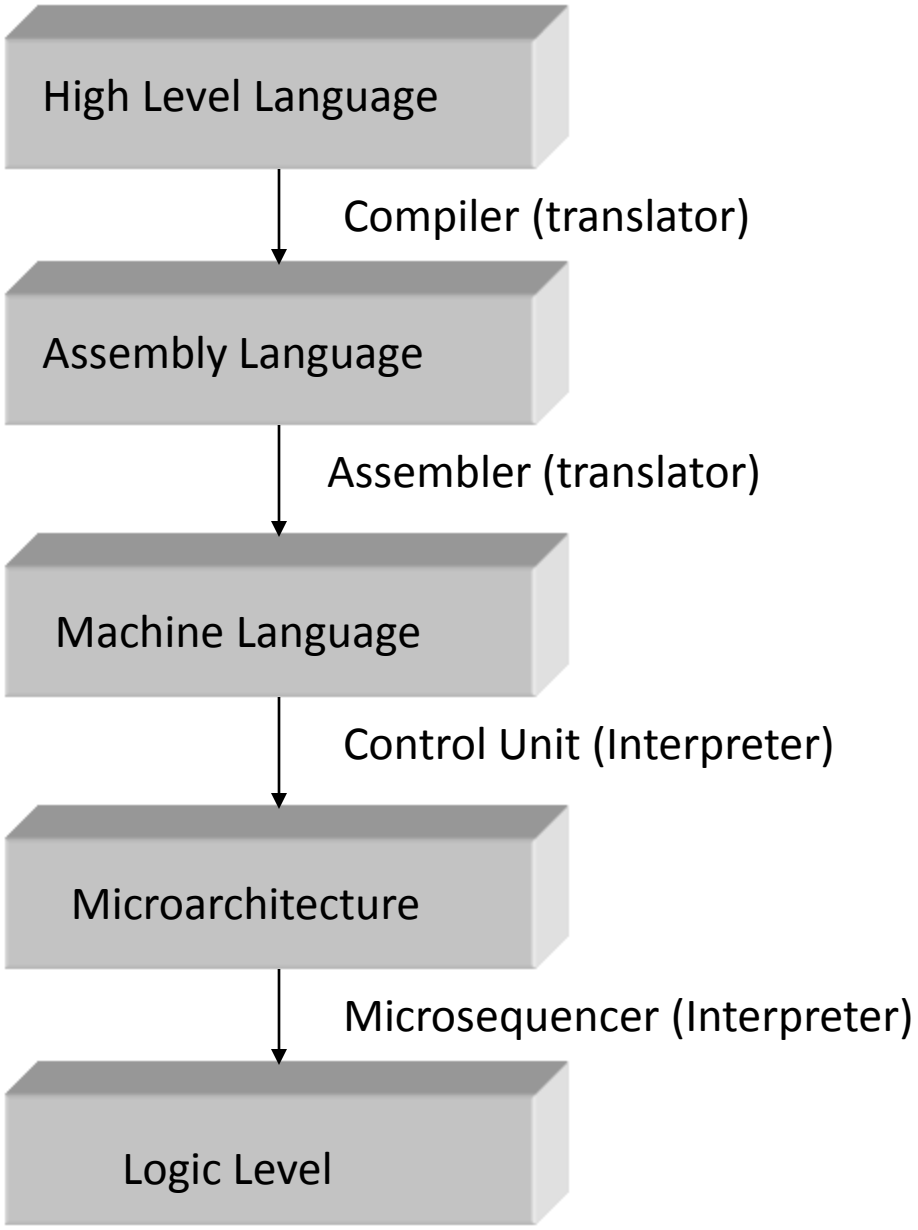
So What Is An Interpreter?



+ Better error diagnostics than compiler
-Slower than machine language code directly executed on the machine

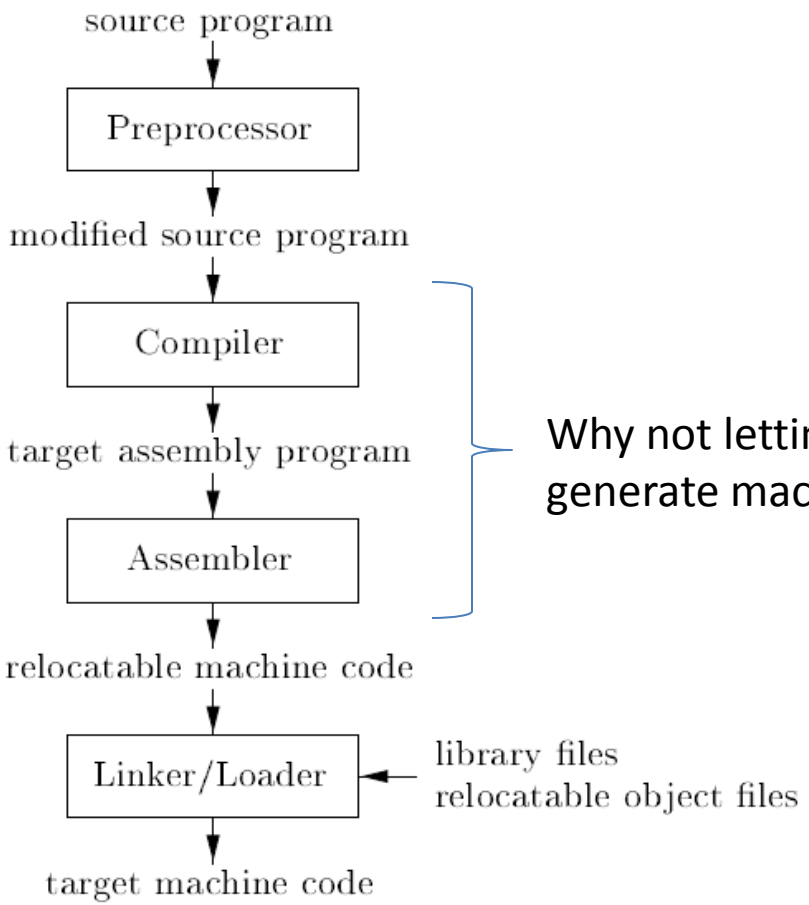

source program
Translator
Compilation
Interpretation
intermediate program
input
Virtual
Machine
output

Problem → Algorithm Development → Programmer



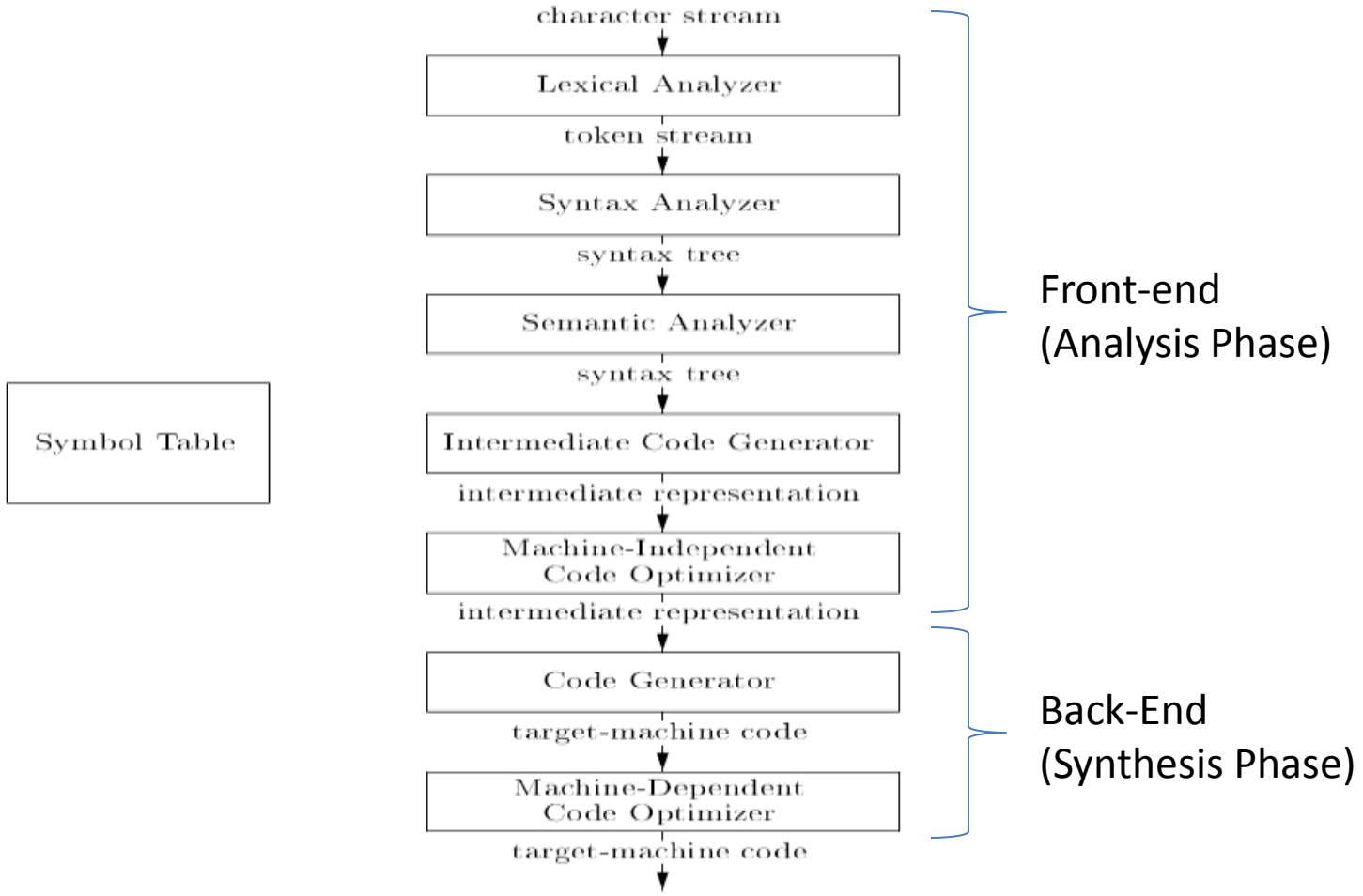
Device Level → Semiconductors → Quantum

Compiler Is Not A One-Man-Show!



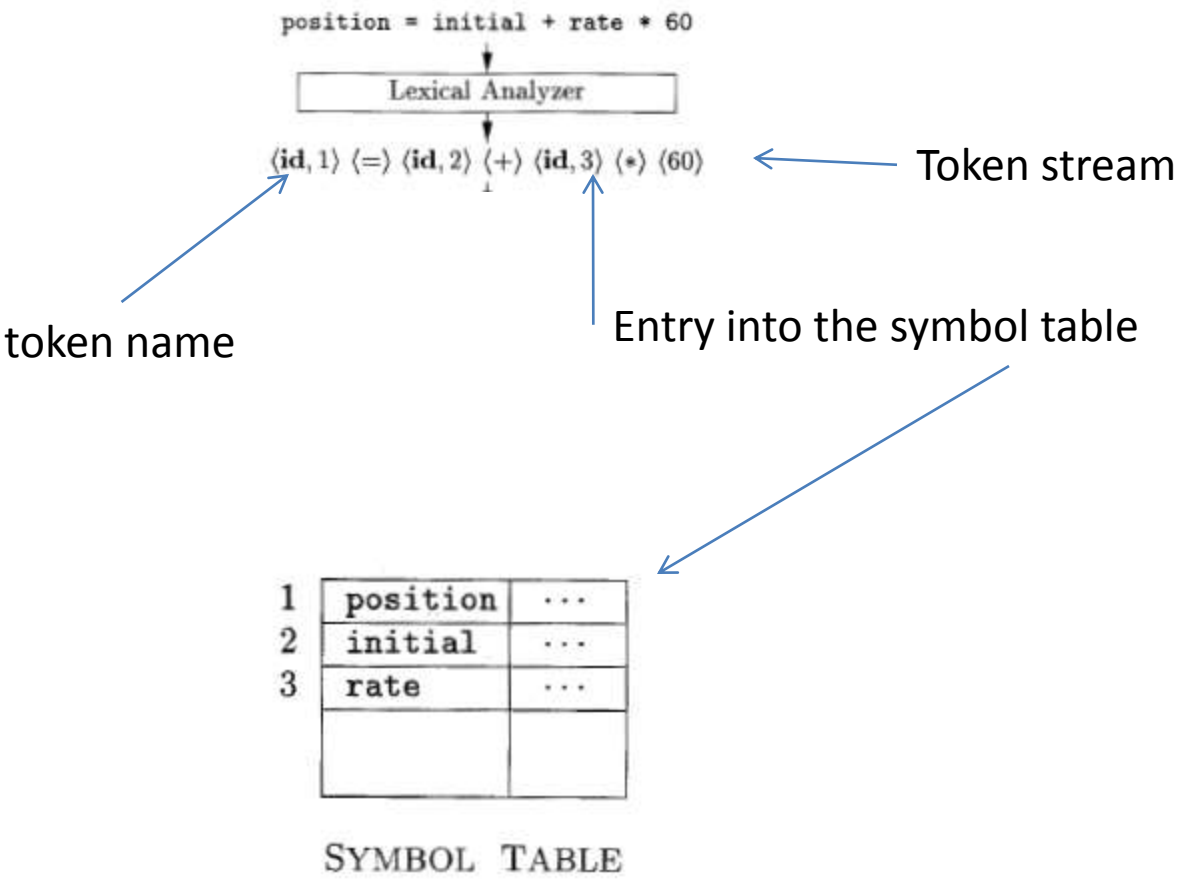
Why not letting the compiler generate machine code directly?

Let's Have A Closer Look: Phases of A Compiler



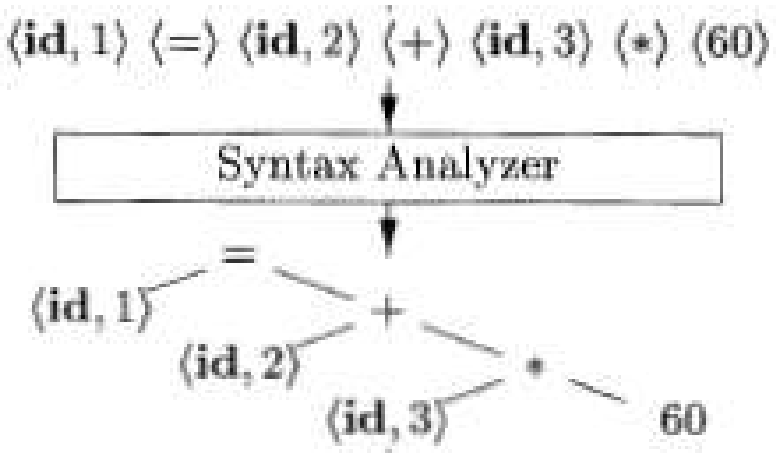
Lexical Analysis

- Reads stream of characters: your program
- Groups the characters into meaningful sequences: lexemes
- For each lexeme, it produces a token
  <token-name, attribute value>
- Blanks are just separators and are discarded
- Filters comments
- Recognizes: keywords, identifier, numbers, …


position = initial + rate * 60
Lexical Analyzer
⟨id, 1⟩ ⟨=⟩ ⟨id, 2⟩ ⟨+⟩ ⟨id, 3⟩ ⟨*⟩ ⟨60⟩
Token stream
token name
Entry into the symbol table
1 position ···
2 initial ···
3 rate ···
SYMBOL TABLE

Syntax Analysis (Parsing)

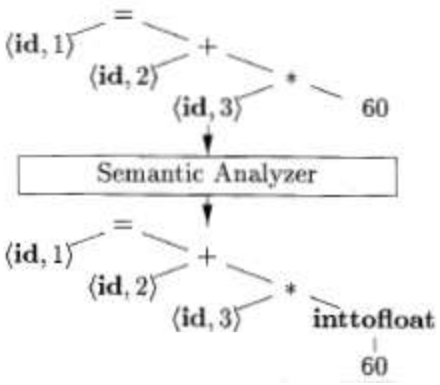
- Uses tokens to build a tree
- The tree shows the grammatical structure of the token stream
- A node is usually an operation
- Node's children are arguments



This is usually called a syntax tree

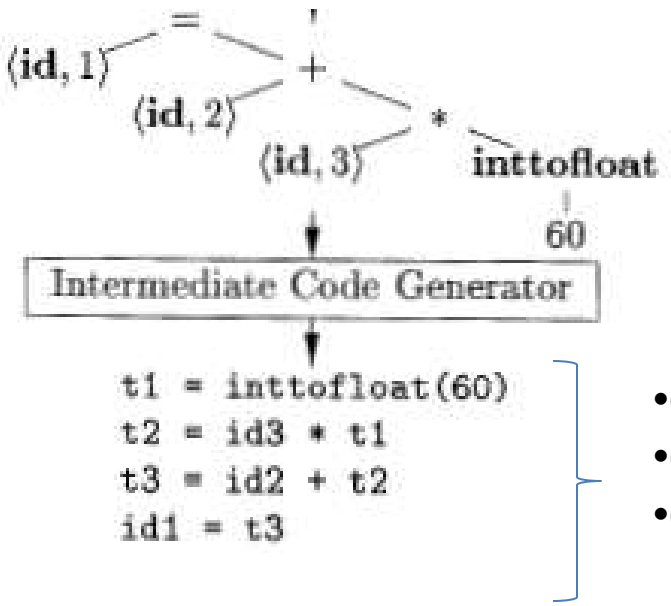
Semantic Analysis

- Uses the syntax tree and symbol tables
- Gathers type information
- Checks for semantic consistency errors



Intermediate Code Generation

- Code for an abstract machine
- Must have two properties
  - Easy to produce
  - Easy to translate to target language

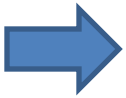


- Called three address code
- One operation per instruction at most
- Compiler must generate temporary names to hold values

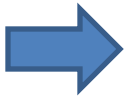
Intermediate Code Optimization (Optional)

- Machine independent
- optimization so that better target code will result

```
t1 = inttofloat (60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
```



```
t1 = id3 * 60.0
t2 = id2 + t1
id1 = t2
```



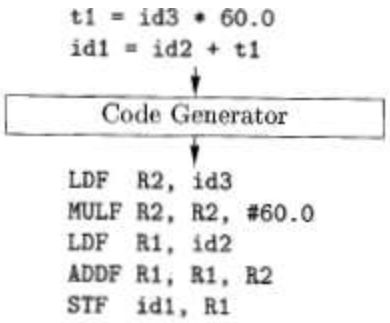
```
t1 = id3 * 60.0
id1 = id2 + t1
```

Instead of inttofloat
we can use 60.0 directly

Do we really need t2?

Code Generation

- Input: the intermediate representation
- Output: target language
- This is the backend, or synthesis phase
- Machine dependent



Qualities of a Good Compiler

- **Correct**: the meaning of sentences must be preserved
- **Robust**: wrong input is the common case
  - compilers and interpreters can't just crash on wrong input
  - they need to diagnose all kinds of errors safely and reliably
- **Efficient**: resource usage should be minimal in two ways
  - the process of compilation or interpretation itself is efficient
  - the generated code is efficient when interpreted
- **Usable**: integrate with environment, accurate feedback
  - work well with other tools (editors, linkers, debuggers, . . .)
  - descriptive error messages, relating accurately to source

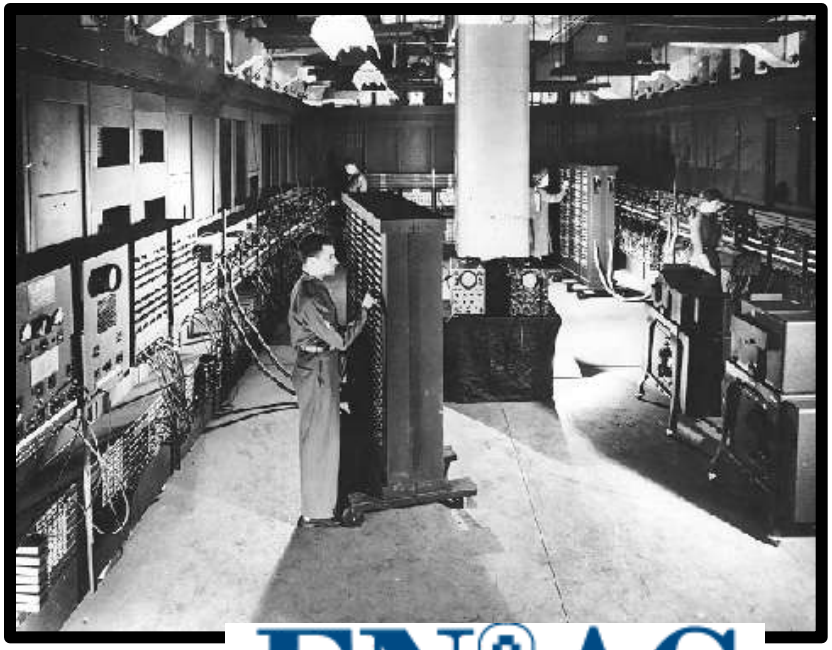
Compilers Optimize Code For:

- Performance/Speed
- Code Size
- Power Consumption
- Fast/Efficient Compilation
- Security/Reliability
- Debugging

Compiler Construction Tools

- Scanner generators: produce lexical analyzer
- Parser generators: automatically produce syntax analyzer
- Syntax-directed translation engines: collection of routines for walking a parse tree and generate intermediate code
- and many more …

A Little Bit of History

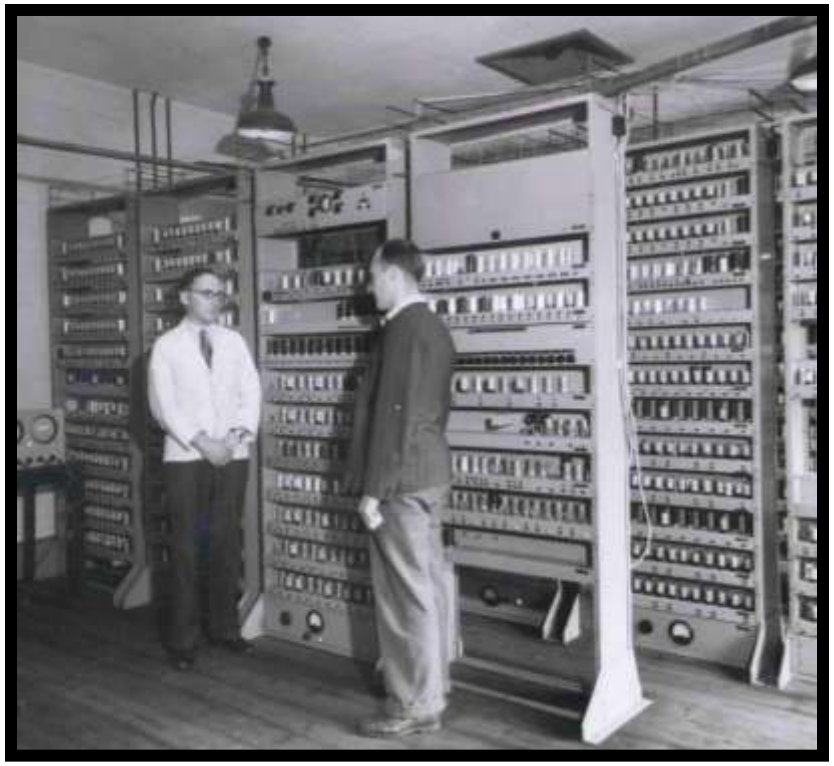


ENIAC

Eckert and Mauchly

- 1st working electronic computer (1946)
- 18,000 Vacuum tubes
- 1,800 instructions/sec
- 3,000 ft^3

A Little Bit of History



EDSAC 1 (1949)

http://www.cl.cam.ac.uk/UoCCL/misc/EDSAC99/

- Maurice Wilkes

1st stored program computer

650 instructions/sec

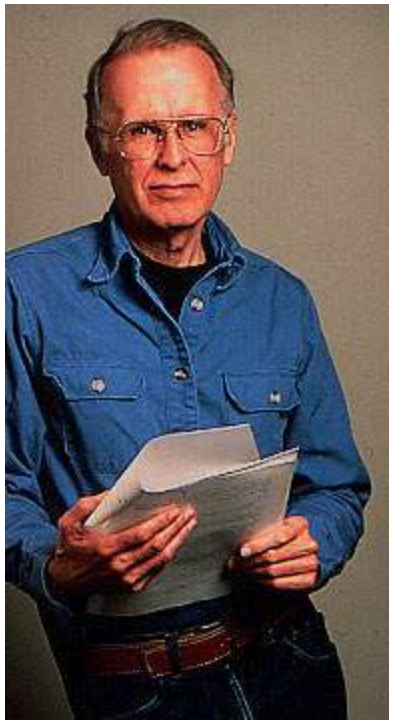
1,400 ft^3

A Little Bit of History

- 1954 IBM developed 704
- All programming done in assembly
- Software costs exceed hardware costs!

A Little Bit of History

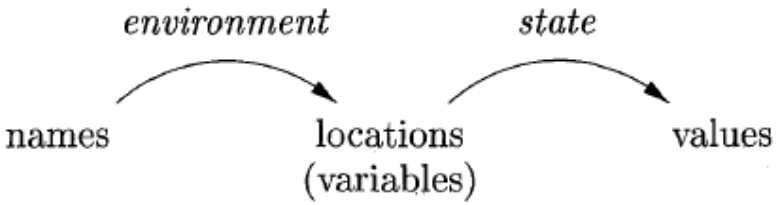
- Fortran I (project 1954-57)
- The main idea is to translate high level language to assembly
- Many thought this was impossible!
- In 1958 more than 50% of software in assembly!
- Development time halved!



John Backus
(December 3, 1924 – March 17, 2007)

A Glimpse At Programming Language Basics

- Static/Dynamic distinction
- Environments and states
  - Environment: mapping names to locations
  - States: mapping from locations to values



- Procedures vs Functions
- Scope

```
main() {
    int a = 1;
    int b = 1;
    {
        int b = 2;
        {
            int a = 3;
            cout << a << b;
        }
        {
            int b = 4;
            cout << a << b;
        }
        cout << a << b;
    }
    cout << a << b;
}
```

B_1

B_2

B_3

B_4

Roadmap

- Today we have mostly discussed chap 1
- Chapter 2 gives an overview of the different phases of a compiler by building the front-end of a simple compiler
- Chapters 3-8 fill the gaps