Compilers

CS143
10:30–11:50 Tuesday/Thursday

Instructor: Fredrik Kjolstad
Slide design by Prof. Alex Aiken, with modifications

The slides in this course are designed by Prof. Alex Aiken, with modifications by Fredrik Kjolstad.

Administrivia

- Syllabus is on-line
  - cs143.stanford.edu
  - Assignment dates will not change
  - Midterm
    - Thursday April 29, via Gradescope
  - Final
    - Tuesday June 3, via Gradescope
- Office hours
  - 20 office hours spread throughout the week
  - On Zoom scheduled through Canvas
- Communication
  - Use discussion forum, email, zoom, office hours

Webpages/servers/

- Course webpage at cs143.stanford.edu
  - Syllabus, lecture slides, handouts, assignments, and policies
- Canvas at canvas.stanford.edu
  - Zoom links to lectures and office hours (see Zoom tab)
  - Lecture recordings available under the Zoom tab -> Cloud Recordings
- Piazza at piazza.com/stanford
  - This is where most questions should be asked
  - Live Q&A during lectures
- Gradescope at gradescope.com
  - This is where you will hand in written assignments and midterm/final
- Computing Resources
  - We will use myth.stanford.edu for the programming assignments

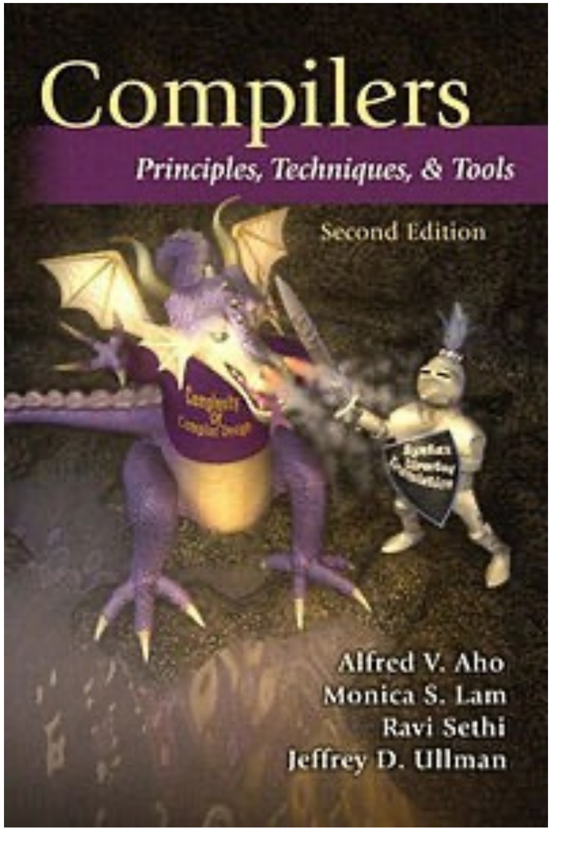
Staff

- Instructor
  - Fredrik Kjolstad

- TAs
  - Caleb Donovick
  - Nikhil Athreya
  - Sicheng Zeng
  - Yinghao Sun

Text

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



Course Structure

- Course has theoretical and practical aspects
- Need both in programming languages!
- Written assignments = theory
- Programming assignments = practice

Academic Honesty

- Don't use work from uncited sources
- We use plagiarism detection software
  - many cases in past offerings

The Course Project

- You will write your own compiler!
- One big project
- … in 4 parts
- Start early! (Start early)

How are Languages Implemented?

- Two major strategies:
  - Interpreters run your program
  - Compilers translate your program

Language Implementations

- Batch compilation systems dominate "low level" languages
  - C, C++, Go, Rust
- "Higher level" languages are often interpreted
  - Python, Ruby
- Some (e.g., Java, Javascript) provide both
  - Interpreter + Just in Time (JIT) compiler

History of High-Level Languages

- 1954: IBM develops the 704
  - Successor to the 701

- Problem
  - Software costs exceeded hardware costs!

- All programming done in assembly

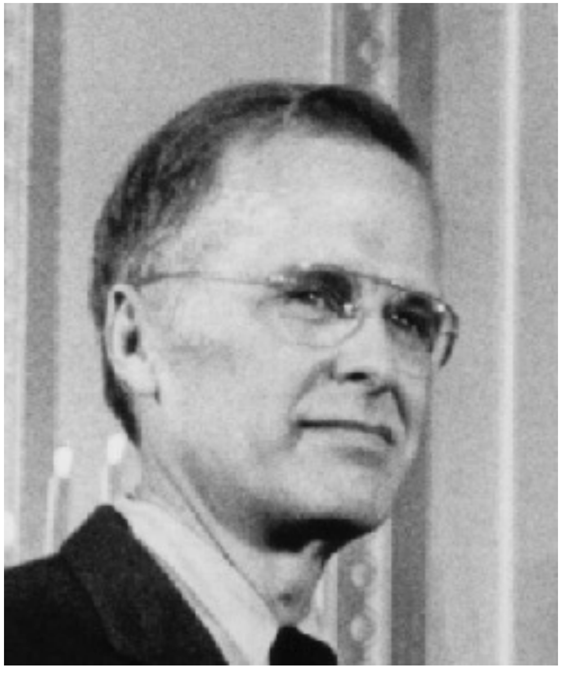
The Solution

- Enter "Speedcoding"
- An interpreter
- Ran 10-20 times slower than hand-written assembly

FORTRAN I

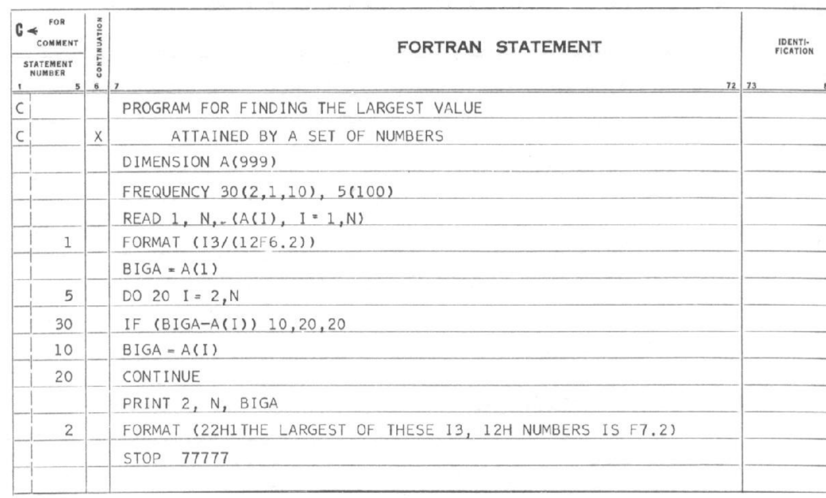
- Enter John Backus

- Idea
  - Translate high-level code to assembly
  - Many thought this impossible
  - Had already failed in other projects



FORTRAN I (Cont.)

- 1954-7
  - FORTRAN I project
- 1958
  - >50% of all software is in FORTRAN
- Development time halved
  - Performance is close to hand-written assembly!



C ← FOR COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

```
C          PROGRAM FOR FINDING THE LARGEST VALUE
C        X      ATTAINED BY A SET OF NUMBERS
           DIMENSION A(999)
           FREQUENCY 30(2,1,10), 5(100)
           READ 1, N, (A(I), I = 1,N)
     1     FORMAT (I3/(12F6.2))
           BIGA = A(1)
     5     DO 20 I = 2,N
    30     IF (BIGA-A(I)) 10,20,20
    10     BIGA = A(I)
    20     CONTINUE
           PRINT 2, N, BIGA
     2     FORMAT (22H1THE LARGEST OF THESE I3, 12H NUMBERS IS F7.2)
           STOP  77777
```

FORTRAN I

- The first compiler
  - Huge impact on computer science

- Led to an enormous body of theoretical and practical work

- Modern compilers preserve the outlines of FORTRAN I

- Can you name a modern compiler?

The Structure of a 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"

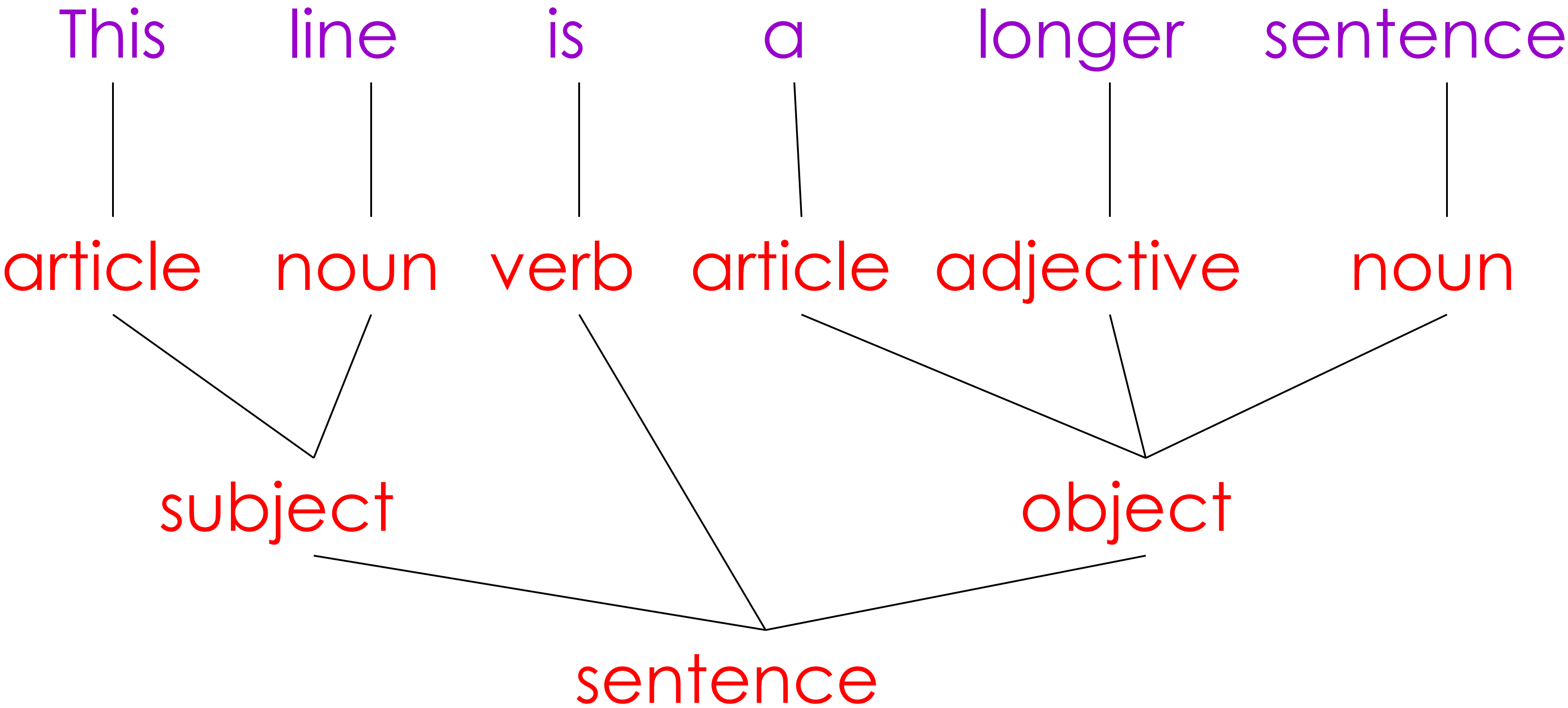
If x == y then z = 1; else z = 2;

- Units:

Parsing

- Once words are understood, the next step is to understand sentence structure
- Parsing = Diagramming Sentences
  - The diagram is a tree

Diagramming a Sentence

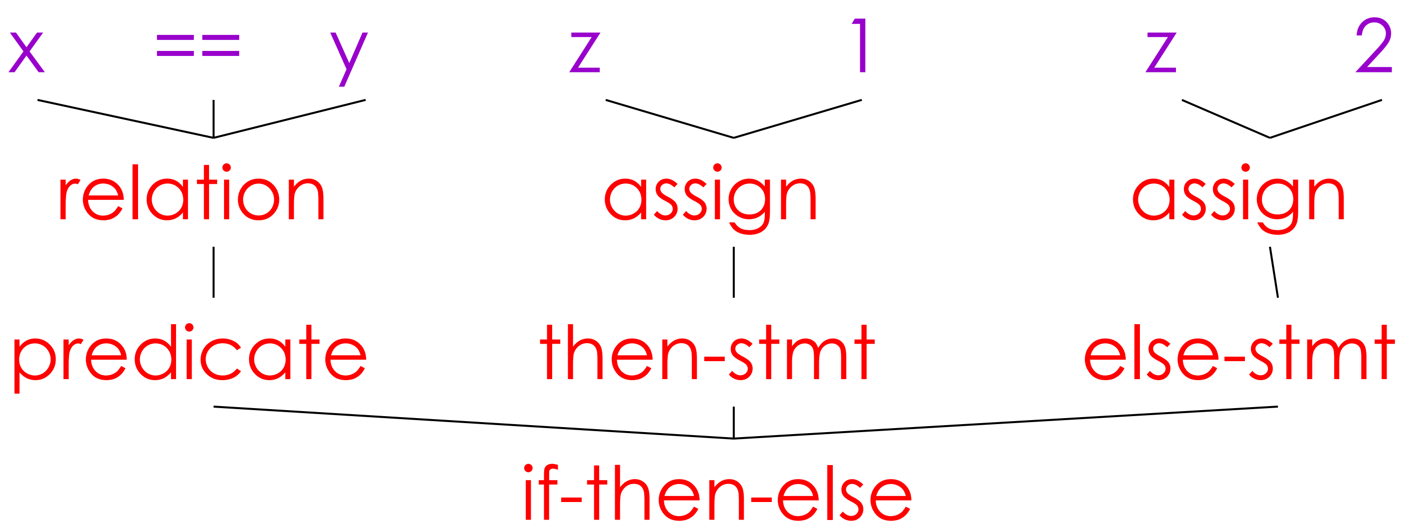


Parsing Programs

- 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?

  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.

- Possible type mismatch between her and Jack
  - If Jack is male

Optimization

- No strong counterpart in English, but akin to editing
- Automatically modify programs so that they
  - Run faster
  - Use less memory
  - In general, to use or conserve some resource
- The project has no optimization component
  - CS243: Program Analysis and Optimization

Optimization Example

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

(the * operator is annihilated by zero)

Code Generation

- Typically produces assembly code
- Generally a translation into another language
  - Analogous to human translation

Intermediate Representations

- Many compilers perform translations between successive intermediate languages
  - All but first and last are intermediate representations (IR) internal to the compiler

- IRs are generally ordered in descending level of abstraction
  - Highest is source
  - Lowest is assembly

Intermediate Representations (Cont.)

- IRs are useful because lower levels expose features hidden by higher levels
  - registers
  - memory layout
  - raw pointers
  - etc.

- But lower levels obscure high-level meaning
  - Classes
  - Higher-order functions
  - Even loops…

Issues

- Compiling is almost this simple, but there are many pitfalls
- Example: How to handle erroneous programs?
- Language design has big impact on compiler
  - Determines what is easy and hard to compile
  - Course theme: many trade-offs in language design

Compilers Today

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

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

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