CS412/413

Introduction to
Compilers and Translators
Spring '00

Lecture 1: Overview

Outline

- About this course
- Introduction to compilers
  - What are compilers?
  - Why should we learn about them?
  - Anatomy of a compiler
- Introduction to lexical analysis
  - Text stream to tokens

Course Information

- Lectures
  - MWF 10:10 - 11:00AM in Hollister 110
- Faculty: Andrew Myers
- Teaching assistants: Nate Nystrom, Alexey Kliger, Andrew Lin
- Course e-mail: cs412@cs.cornell.edu
- Course web page: http://courses.cs.cornell.edu/cs412/2000sp

CS 413 is required!

Textbooks

- Required text
  - Modern Compiler Implementation in Java. Andrew Appel.
- Optional texts
  - Compilers -- Principles, Techniques and Tools. Aho, Sethi and Ullman (The Dragon Book)
  - Advanced Compiler Design and Implementation. Steve Muchnick.
- Java reference
  - Java Language Specification. James Gosling, Bill Joy, and Guy Steele.
- On reserve in Engineering Library

Work

- Homeworks: 4, 20% total
  - 5/5/5/5
- Programming Assignments: 6, 50%
  - 5/7/8/10/10/10
- Exams: 2 prelims, 30%
  - 15/15
  - No final exam

Homeworks

- Three assignments in first half of course; one homework in second half
- *Not* done in groups—you may discuss however

Projects

- Six programming assignments
- Groups of 3-4 students
  - same grade for all
- Group information due Wednesday
  - we will respect consistent preferences
- Java will be implementation language

All Assignments

- Due at beginning of class
- Late homeworks, programming assignments increasingly penalized
- Project files must be available at noon on the same day

Why take this course?

- CS412 is an elective course
- Expect to learn:
  - practical applications of theory
  - parsing
  - deeper understanding of code
  - manipulation of complex data structures
  - how high-level languages are implemented in machine language
  - a little programming language semantics
  - Intel x86 architecture, Java
  - how to be a better programmer (esp. in groups)

What are Compilers?

- Translators from one representation of a program to another
- Typically: high-level source code to machine language (object code)
- Not always
  - Java compiler: Java to interpretable bytecodes
  - Java JIT: bytecode to executable image

Source Code

- Source code: optimized for human readability
  - expressive: matches human notions of grammar
  - redundant to help avoid programming errors
  - often non-deterministic

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

Machine code

- Optimized for hardware
  - Redundancy, ambiguity reduced
  - Information about intent lost
  - Assembly code ≈ machine 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
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
```


How to translate?

- Source code and machine code mismatch
- Some languages farther from machine code than others ("higher-level")
- Goal:
  - high level of abstraction
  - best performance for concrete computation
  - reasonable translation efficiency (<< O(n^3))
  - maintainable code

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
```

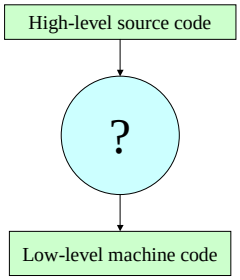
Optimized Code

```
s4addq $16,0,$0
mull $16,$0,$0
addq $16,1,$16
mull $0,$16,$0
mull $0,$16,$0
ret $31,($26),1
```


Correctness

- Programming languages describe computation precisely
- Therefore: translation can be precisely described (a compiler can be correct)
- Correctness is very important!
  - non-trivial: programming languages are expressive
  - implications for development cost, security
  - this course: techniques for building correct compilers

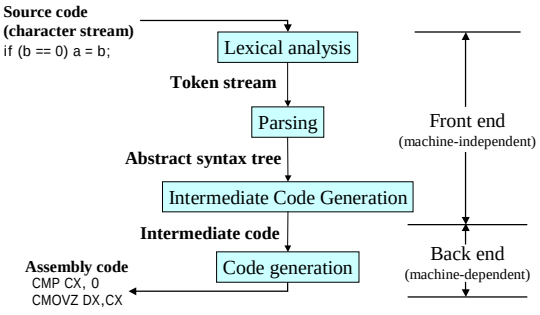
How to translate effectively?



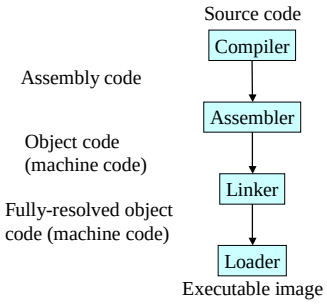
Idea: Translate in Steps

- Series of program representations
- Intermediate representations optimized for program manipulations of various kinds (checking, optimization)
- More machine-specific, less language-specific as translation proceeds

Simplified Compiler Structure



Big picture

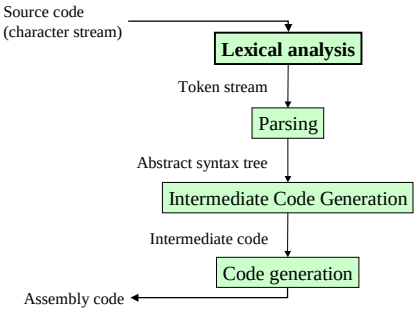


Schedule

- Schedule is available from web page

Lexical analysis and parsing:	5
Semantic analysis:	5
Intermediate code:	4
Prelim #1	
Code generation:	3
Separate compilation and objects:	4
Optimization:	8
Prelim #2	
Run-time, link-time support:	2
Advanced topics:	8

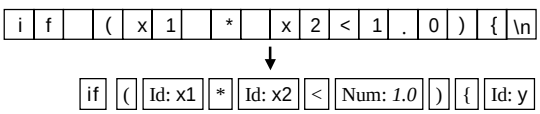
First step: Lexical Analysis



What is Lexical Analysis?

- Converts character stream to token stream <Token type, attribute>

```
if  (x1 * x2<1.0) {
    y = x1;
}
```



Token stream

- Gets rid of whitespace, comments
- <Token type, attribute>
- <Id, “x”> <Float, *1.0e0*>
- Token location preserved for debugging, error messages (line number)

- Issues:
  - how to specify tokens?
  - how to implement tokenizer