CS412/413

Introduction to
Compilers and Translators
Spring 2002

Lecture 1: Overview

Outline

- Course Organization
  - General course information
  - Homework & project information
- Introduction to Compilers
  - What are compilers?
  - Why do we need compilers?
  - General compiler structure

General Information

When	MWF 10:10 - 11:00AM
Where	HO 110
Faculty	Radu Rugina
Teaching Assistants	Prakash Linga
	Michael Polyakov
Admin Assistant	Juanita Heyerman
Email	cs412@cs.cornell.edu
Web page	http://www.cs.cornell.edu/courses/cs412

Important

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

Textbooks

- Required text
  - Tiger Book: Modern Compiler Implementation in Java, by Andrew Appel
- Optional texts
  - Dragon Book: Compilers -- Principles, Techniques and Tools, by Aho, Sethi and Ullman
  - Whale Book: Advanced Compiler Design and Implementation, by Steve Muchnick
- All are on reserve in Engineering Library

Work

- Theory:
  - Homeworks = 20%
    - 4 homeworks: 5/5/5/5
  - Exams = 35%
    - 2 prelims: 17/18; no final exam
- Practice:
  - Programming Assignments = 45%
    - 6 assignments: 5/8/8/8/8/8

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 information:
  - Designed language ≅ a subset of Java
  - Generated code = assembly x86
  - Implementation language = Java
- Six 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 the class)
  - Project files: electronic turn in (CSUGLAB directory)
- Late homeworks, programming assignments increasingly penalized
  - Penalty linearly increasing up to 5 days:
  - 1 day: 10%, 2 days: 20%, 3 days: 30%, 4 days: 40%, 5 days: 50%, >5 days: 50%
  - Extensions can be granted, but must be approved 2 days in advance

Why Take This Course?

- CS412/413 is an elective course
- Reason #1: better understand compilers
  - Understand the code structure
  - Understand the language semantics
  - Understand the 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 which use these models
  - Practice:
    - Apply theoretical notions to build a real compiler
    - Better understand why "theory and practice are the same in theory; in practice they are different"

Why Take This Course? (ctd.)

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

What Are Compilers?

- Compilers = translate information from one representation to another
- Usually information = program
- So compilers=translators, but typically:
  - Compilers refer to the translation from high-level source code to low-level code (e.g. object code)
  - Translators refer to the transformation at the same level of abstraction

Examples

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

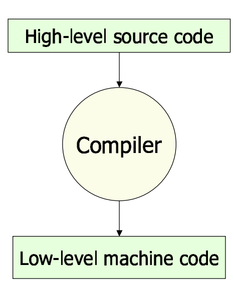
In This Class

- 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 (≅ 50 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;
}
```

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


Translation Efficiency

- Goal: generate machine code which describes the same computation as the source code
- Is there a unique translation?
  NO!
- Is there an algorithm for an "ideal translation"? (ideal = either fastest or smallest generated code)
  NO!
- 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
```

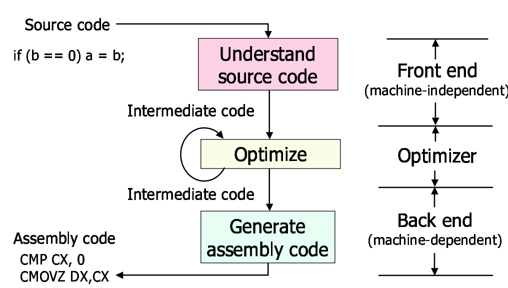

Translation Correctness

- 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 proved to ensure correct translation

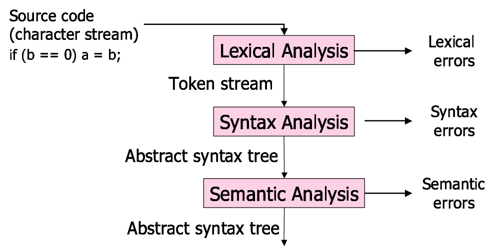
How To Translate?

- 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

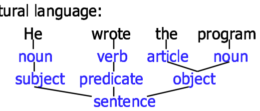


Analogy

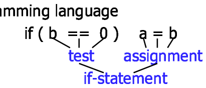
- Front end can be explained by analogy to the way humans understand natural languages
- Lexical analysis
  - Natural language: "He wrote the program"
    words: "he" "wrote" "the" "program"
  - Programming language "if (b == 0) a = b"
    tokens: "if" "(" "b" "==" "0" ")" "a" "=" "b"

Analogy (ctd)

- Syntactic analysis
  - Natural language:



  - Programming language



Analogy (ctd)

- Semantic analysis
  - Natural language:

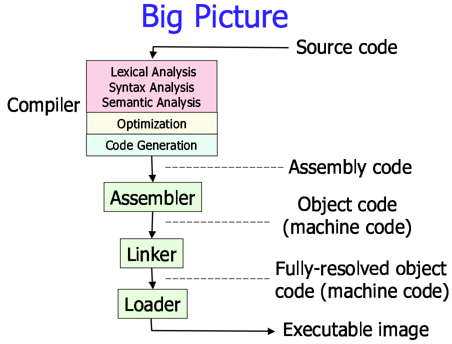
    He wrote the computer
    noun verb article noun

    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



Schedule

Lexical analysis	3 lectures
Syntax analysis	5 lectures
Semantic analysis	4 lectures
Intermediate code	3 lectures
Prelim #1	
Analysis/optimizations	9 lectures
Code generation	5 lectures
Objects	3 lectures
Prelim #2	
Advanced topics	6 lectures