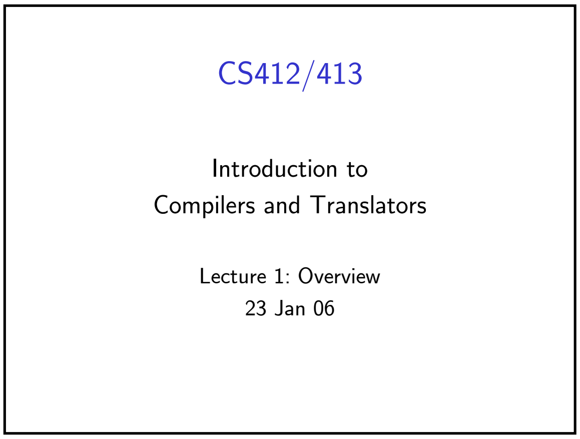
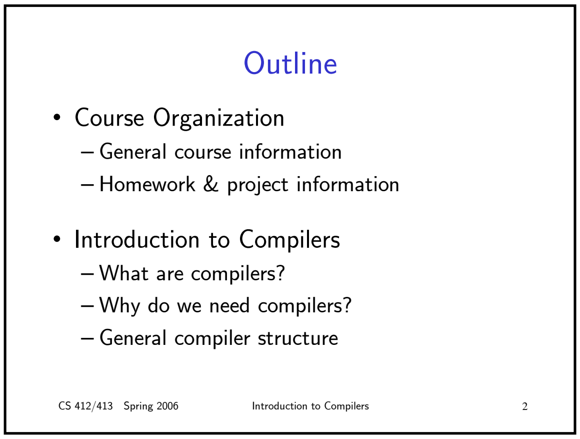


CS412/413

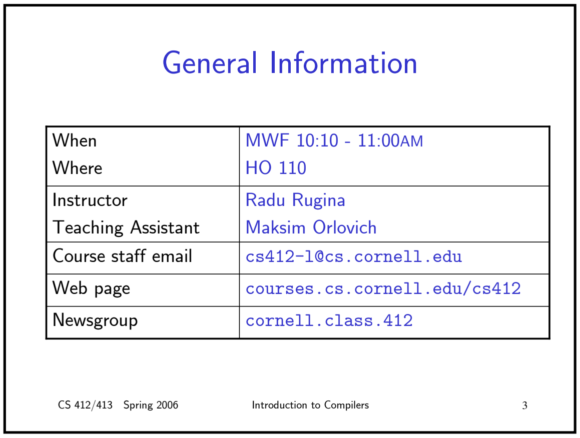
Introduction to
Compilers and Translators

Lecture 1: Overview
23 Jan 06



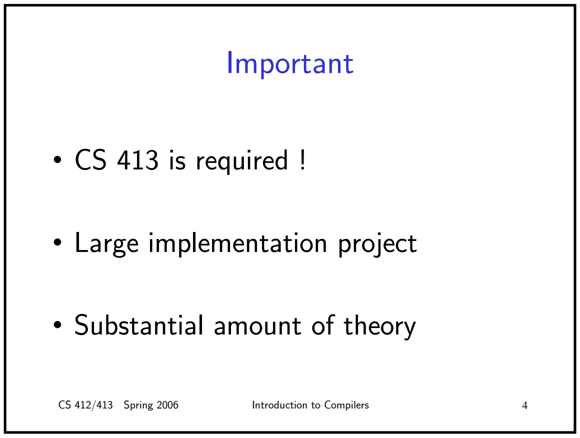
Outline

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



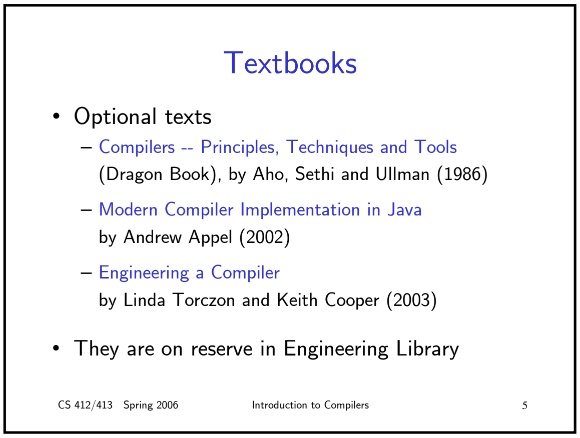
General Information

When Where	MWF 10:10 - 11:00AM HO 110
Instructor Teaching Assistant	Radu Rugina Maksim Orlovich
Course staff email	cs412-l@cs.cornell.edu
Web page	courses.cs.cornell.edu/cs412
Newsgroup	cornell.class.412



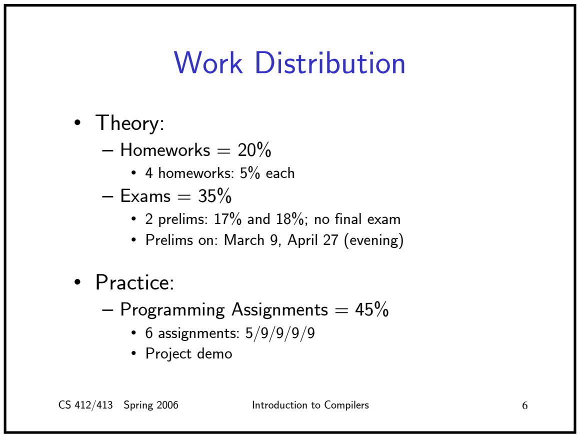
Important

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



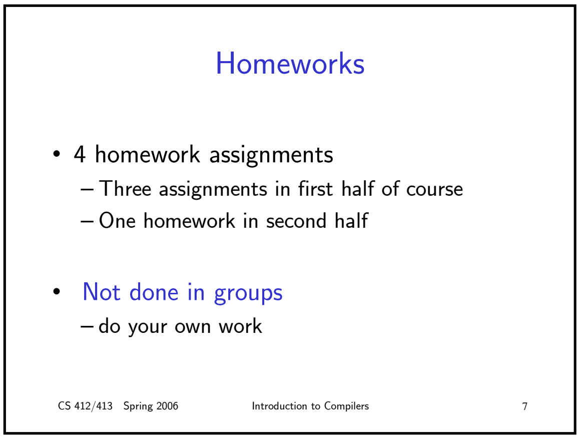
Textbooks

- 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 are on reserve in Engineering Library



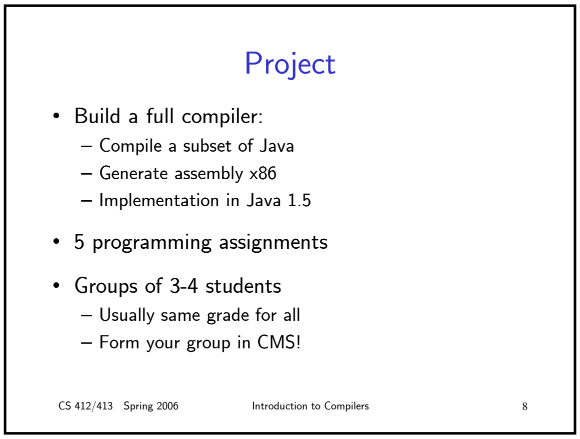
Work Distribution

- Theory:
  - Homeworks = 20%
    - 4 homeworks: 5% each
  - Exams = 35%
    - 2 prelims: 17% and 18%; no final exam
    - Prelims on: March 9, April 27 (evening)
- Practice:
  - Programming Assignments = 45%
    - 6 assignments: 5/9/9/9/9
    - Project demo



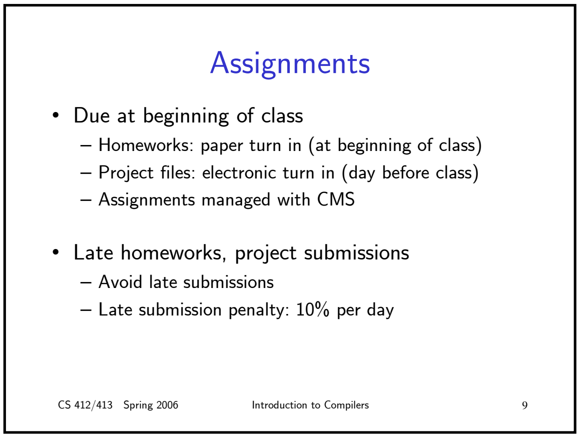
Homeworks

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



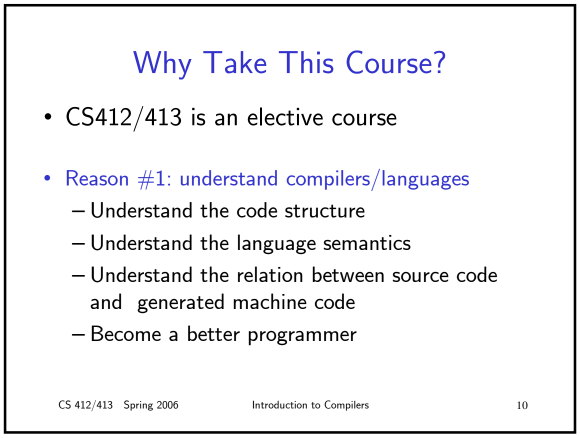
Project

- Build a full compiler:
  - Compile a subset of Java
  - Generate assembly x86
  - Implementation in Java 1.5
- 5 programming assignments
- Groups of 3-4 students
  - Usually same grade for all
  - Form your group in CMS!



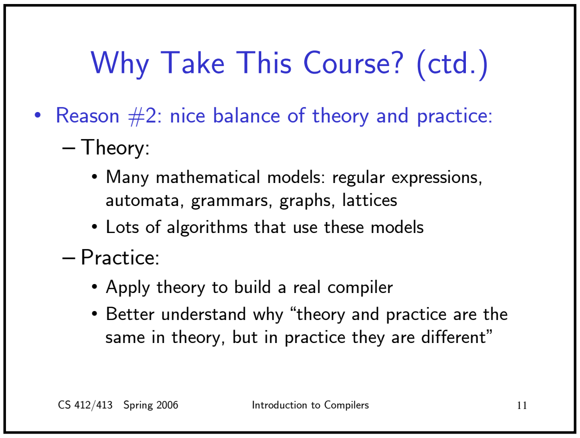
Assignments

- Due at beginning of class
  - Homeworks: paper turn in (at beginning of class)
  - Project files: electronic turn in (day before class)
  - Assignments managed with CMS
- Late homeworks, project submissions
  - Avoid late submissions
  - Late submission penalty: 10% per day



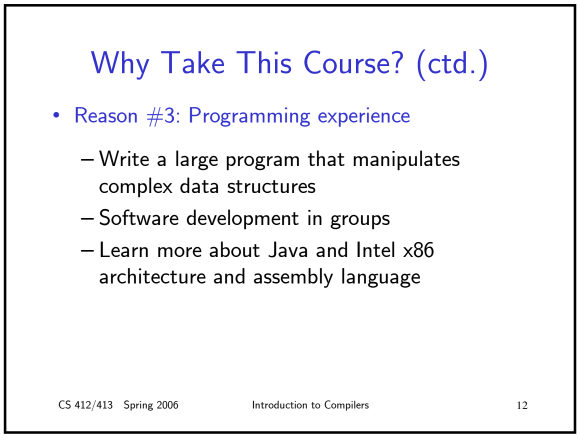
Why Take This Course?

- CS412/413 is an elective course
- Reason #1: understand compilers/languages
  - 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:
    - Many mathematical models: regular expressions, automata, grammars, graphs, lattices
    - Lots of algorithms that use these models
  - Practice:
    - Apply theory to build a real compiler
    - Better understand why “theory and practice are the same in theory, but in practice they are different”



Why Take This Course? (ctd.)

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

What Are Compilers?

- Compilers = translate information from one representation into another
- Usually information = program
- 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:
  - latex (document compiler) :
    - Transforms a LaTeX document into DVI printing commands
  - C-to-Hardware compiler:
    - Generates hardware circuits for C programs
- Translators:
  - f2c : Fortran-to-C translator (high-level)
  - latex2html : LaTeX-to-HTML (documents)
  - dvi2ps: DVI-to-PostScript (low-level)

Related Paradigms

- Interpretation
  - Interpreter executes source program
  - You've seen them in CS211, CS312
- Compilation for a Virtual Machine
  - E.g., Java bytecode compilation
  - Portable compilation
- JIT (Just-in-Time) Compilation
  - Dynamic compilation

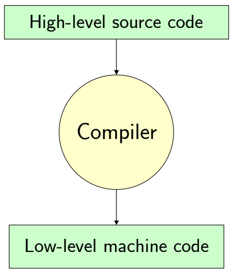
In This Class

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

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 a few cases when people manually write assembly code
  - E.g. to access low-level machine resources such as 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
```

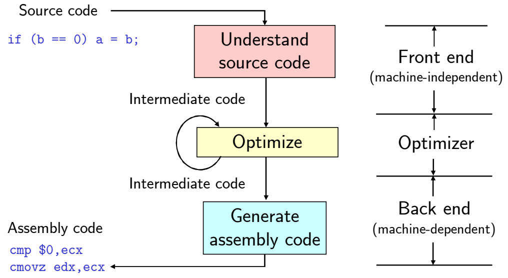
Translation Correctness

- 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 proved to ensure correct translation

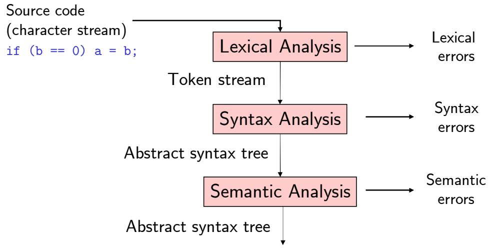
How To Translate?

- Translation is a complex process
  - source language and generated code are very different
- 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

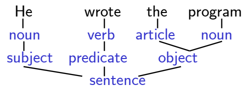


Analogy

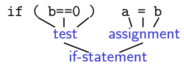
- Front end can be explained by analogy to the way humans understand natural languages
- Lexical analysis
  - Natural language: "He wrote the program"
    words: "he" "wrote" "the" "program"
  - Programming language "`if (b == 0) a = b`"
    tokens: "`if`" "`(`" "`b`" "`==`" "`0`" "`)`" "`a`" "`=`" "`b`"

Analogy (ctd)

- Syntactic analysis
  - Natural language:



  - Programming language



Analogy (ctd)

- Semantic analysis
  - Natural language:

He	wrote	the	computer
noun	verb	article	noun

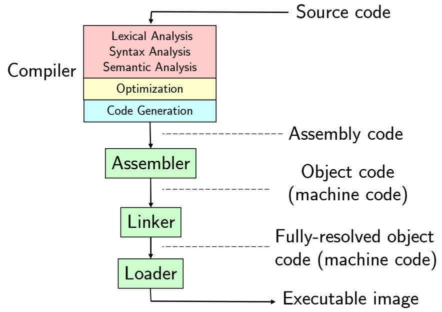
    Syntax is correct; semantics is wrong!

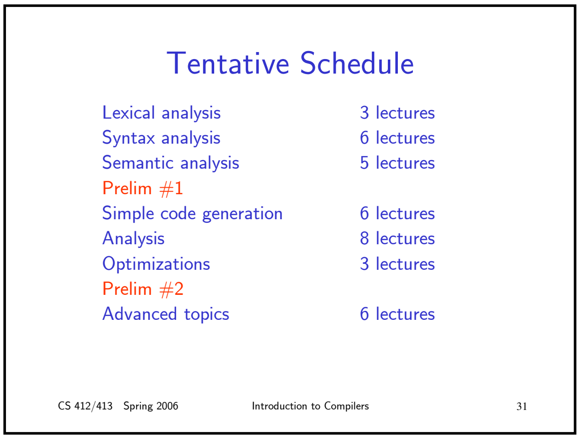
  - Programming language

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

    if a is an integer and `foo` is a method, the compiler will complain.

Beyond Assembly Code





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
Prelim #2	
Advanced topics	6 lectures