Lecture 1
Introduction

I. Why Study Compilers?

II. Course Syllabus

Chapters 1.1-1.5, 8.4, 8.5, 9.1
Reasons for Studying Compilers

- **Compilers are important**
  - An essential programming tool
    - Improves software productivity by hiding low-level details
  - A tool for designing and evaluating computer architectures
    - Inspired RISC, VLIW machines
    - Machines' performance measured on compiled code
  - Techniques for developing other programming tools
    - Examples: error detection tools
  - Little languages and program translations can be used to solve other problems

- **Compilers have impact: affect all programs**

Compiler Study Trains Good Developers

*Excellent software engineering case study*

- Optimizing compilers are hard to build
  - Input: all programs
  - Objectives:
    - **Methodology for solving complex real-life problems**
      - Key to success: Formulate the right approximation!
        - Desired solutions are often NP-complete / undecidable
      - Where theory meets practice
        - Can't be solved by just pure hacking
          - theory aids generality and correctness
        - Can't be solved by just theory
          - experimentation validates and provides feedback to problem formulation
  - Reasoning about programs, reliability & security makes you a better programmer

  *There are programmers, and there are tool builders ...*
Example

• Tools for web application security vulnerabilities
• PQL: a general language for describing information flow of interest
• Static techniques to locate errors automatically
• Illustrates:
  – Exciting research area
  – Importance of programming tools
  – Sophistication of static analysis techniques
  – What static analysis looks like
  – Use of little languages
  – Combination of theory and hacking

Use of Mathematical Abstraction

Programs

static statements
dynamic execution

generated code

Mathematical Model

graphs
matrices
integer programs
relations

solutions

abstraction

• Design of mathematical model & algorithm
  – Generality, power, simplicity and efficiency
# Course Syllabus

## 1. Basic compiler optimizations

<table>
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<tr>
<th>Goal</th>
<th>Eliminates redundancy in high-level language programs</th>
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<tr>
<td></td>
<td>Allocates registers</td>
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<td></td>
<td>Schedules instructions (for instruction-level parallelism)</td>
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<tr>
<td>Scope</td>
<td>Simple scalar variables, intraprocedural, flow-sensitive</td>
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<tr>
<td>Theory</td>
<td>Data-flow analysis (graphs &amp; solving fix-point equations)</td>
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## 2. Pointer alias analysis

<table>
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<th>Goal</th>
<th>Used in program understanding, concrete type inference in OO programs (resolve target of method invocation, inline, and optimize)</th>
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<tr>
<td>Scope</td>
<td>Pointers, interprocedural, flow-insensitive</td>
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<tr>
<td>Theory</td>
<td>Relations, Binary decision diagrams (BDD)</td>
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## 3. Parallelization and memory hierarchy optimization

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<th>Parallelizes sequential programs (for multiprocessors)</th>
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<tr>
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<td>Optimizes for the memory hierarchy</td>
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<tr>
<td>Scope</td>
<td>Arrays, loops</td>
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<tr>
<td>Theory</td>
<td>Linear algebra</td>
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## 4. Garbage collection (run-time system)


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# Tentative Course Schedule

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<td>Data-flow analysis: theoretic foundation</td>
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<td>4</td>
<td>(joeq)</td>
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<td>Optimization: constant propagation</td>
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<td>Optimization: redundancy elimination</td>
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<td>Register allocation</td>
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<td>Basic concepts</td>
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Course Emphasis

- **Methodology:** apply the methodology to other real life problems
  - Problem statement
    - Which problem to solve?
  - Theory and Algorithm
    - Theoretical frameworks
    - Algorithms
  - Experimentation: Hands-on experience

- **Compiler knowledge:**
  - Non-goal: how to build a complete optimizing compiler
  - Important algorithms
  - Exposure to new ideas
  - Background to learn existing techniques

Assignment by next class (no need to hand in)

- Think about how to build a compiler that converts the code on page 11 to page 12
  - (Read Chapter 9.1 for introduction of the optimizations)

- **Example:** Bubblesort program that sorts array $A$ allocated in static storage

```c
for (i = n-2; i >= 0; i--) {
    for (j = 0; j <= i; j++) {
        if (A[j] > A[j+1]) {
            temp = A[j];
            A[j] = A[j+1];
            A[j+1] = temp;
        }
    }
}
```
Code Generated by the Front End

i := n-2
S5: if i<0 goto s1
j := 0
t14 = 4*t13
t15 = &A
t16 = t15+t14
s4: if j>i goto s2
t1 = 4*j
t17 = *t16 ;A[j+1]
t18 = 4*j
t2 = &A
t3 = t2+t1
t19 = &A
*t3 = A[j]
t20 = t19+t18 ;&A[j]
t5 = j+1
*t20 = t17 ;A[j]=A[j+1]
t6 = 4*t5
t21 = j+1
t7 = &A
t22 = 4*t21
t8 = t7+t6
t23 = &A
t9 = *t8 ;A[j+1]
t24 = t23+t22
if t4 <= t9 goto s3
*t24 = temp ;A[j+1]=temp
t10 = 4*j
s3: j = j+1
t11 = &A
goto s4
t12 = t11+t10
s2: i = i-1
temp = *t12 ;temp=A[j]
goto s5
s1:
(t4=*t3 means read memory at address in t3 and write to t4: *t20=t17: store value of t17 into memory at address in t20)

After Optimization

Result of applying:
  global common subexpression
  loop invariant code motion
  induction variable elimination
  dead-code elimination
  to all the scalar and temp. variables

These traditional optimizations can make a big difference!