Lecture 1

Introduction

I. Why Study Compilers?
II. Course Syllabus

Chapters 1.1-1.5, 8.4, 8.5, 9.1

I. Why Study Compilers?

Reasons for Studying Compilers

- **Compilers are important**
  - An essential programming tool
    - Improves software productivity by hiding low-level details
    - Domain-specific languages for encapsulating domain expertise
  - A tool for designing and evaluating computer architectures
    - Inspired RISC, VLIW machines
    - Machines' performance measured on compiled code
  - Techniques for developing other programming tools
    - Example: error detection tools
  - Program translation can be used to solve other problems
    - Example: Binary translation (processor change, adding virtualization support)
  - Implementation of domain-specific languages
    - CAD, database, graphics, networking, bio-computation, IoT, …
- **Compilers have impact: affect all programs**

Compiler Study Trains Good Developers

Excellent software engineering case study

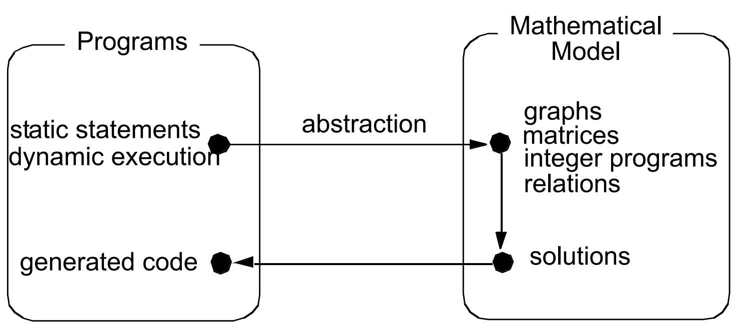
- **Optimizing compilers are hard to build**
  - Input: all programs
  - Objectives:
- **Methodology for solving complex real-life problem s**
  - Key to success: Formulate the right approximation!
    - Desired solutions are often NP-complete / undecidable
  - Where theory meets practice
    - Can't 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 domain-specific languages
  - Combination of theory and hacking

Use of Mathematical Abstraction



- **Design of mathematical model & algorithm**
  - Generality, power, simplicity and efficiency

Course Syllabus

1. **Basic compiler optimizations**

Goal	Eliminates redundancy in high-level language programs Allocates registers Schedules instructions (for instruction-level parallelism)
Scope	Simple scalar variables, intraprocedural, flow-sensitive
Theory	Data-flow analysis (graphs & solving fix-point equations)

2. **Pointer alias analysis**

Goal	Used in program understanding, concrete type inference in OO programs (resolve target of method invocation, inline, and optimize)
Scope	Pointers, interprocedural, flow-insensitive
Theory	Relations, Binary decision diagrams (BDD)

3. **Parallelization and memory hierarchy optimization**

Goal	Parallelizes sequential programs (for multiprocessors) Optimizes for the memory hierarchy
Scope	Arrays, loops
Theory	Linear algebra

4. **Domain-specific languages: graphs, image processing, internet of things**
5. **Garbage collection (run-time system)**

Tentative Course Schedule

1	Course introduction	
2	Basic compilers	Data-flow analysis: introduction
3		Data-flow analysis: theoretic foundation
4		Optimization: constant propagation
5		(joeq)
6		Optimization: redundancy elimination
7		Register allocation
8		Scheduling: non-numerical code
9		Scheduling: software pipelining
10		Dynamic compilation
11	Pointer alias analysis	Formulation
12		BDDs in pointer analysis
13	Domain specific languages	A graph analysis language
14	Parallelism/Locality	Introduction
15		Affine partitioning
16	Domain specific languages	An image processing language
17		A language for Internet of Things
18	Garbage Collection	Basic concepts
19		Optimizations

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

```
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                        t13 = j+1
S5:   if i<0 goto s1                  t14 = 4*t13
      j := 0                          t15 = &A
s4:   if j>i goto s2                  t16 = t15+t14
      t1 = 4*j                        t17 = *t16      ;A[j+1]
      t2 = &A                         t18 = 4*j
      t3 = t2+t1                      t19 = &A
      t4 = *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!

```
      i = n-2
      t27 = 4*i
      t28 = &A
      t29 = t27+t28
      t30 = t28+4
S5:   if t29 < t28 goto s1
      t25 = t28
      t26 = t30
s4:   if t25 > t29 goto s2
      t4 = *t25          ;A[j]
      t9 = *t26          ;A[j+1]
      if t4 <= t9 goto s3
      temp = *t25        ;temp=A[j]
      t17 = *t26         ;A[j+1]
      *t25 = t17         ;A[j]=A[j+1]
      *t26 = temp        ;A[j+1]=temp
s3:   t25 = t25+4
      t26 = t26+4
      goto S4
S2:   t29 = t29-4
      goto s5
s1:
```