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Program Optimization

TU München

Winter 2009/10

Organization

Dates:

Lecture:	Monday, 12:15-13:45
	Wednesday, 12:15-13:45
Tutorials:	Thursday, 16:30-18:00
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Material:	slides, recording :-)
	simulator environment

Grades:

- Bonus for homeworks
- written exam

Proposed Content:

1. Avoiding redundant computations
   - → available expressions
   - → constant propagation/array-bound checks
   - → code motion
2. Replacing expensive with cheaper computations
   - → peep hole optimization
   - → inlining
   - → reduction of strength
   - ...

3. Exploiting Hardware

   → Instruction selection

   → Register allocation

   → Scheduling

   → Memory management

0 Introduction

Observation 1: Intuitive programs often are inefficient.

Example:

```
void swap (int i, int j) {
     int t;
     if (a[i] > a[j]) {
          t = a[j];
          a[j] = a[i];
          a[i] = t;
        }
     }
```

Inefficiencies:

- Addresses `a[i], a[j]` are computed three times :-(
- Values `a[i], a[j]` are loaded twice :-(

Improvement:

- Use a pointer to traverse the array `a`;
- store the values of `a[i], a[j]`!

```
void swap (int *p, int *q) {
     int t, ai, aj;
     ai = *p; aj = *q;
     if (ai > aj) {
         t = aj;
         *q = ai;
         *p = t;    // t can also be
        }           // eliminated!
     }
```

Observation 2:

Higher programming languages (even C :-) abstract from hardware and efficiency.

It is up to the compiler to adapt intuitively written program to hardware.

Examples:

- ... Filling of delay slots;
- ... Utilization of special instructions;
- ... Re-organization of memory accesses for better cache behavior;
- ... Removal of (useless) overflow/range checks.

Observation 3:

Programm-Improvements need not always be correct :-(

Example:

```
y = f() + f();   ⟹   y = 2 * f();
```

Idea:

Save second evaluation of `f()` ...

Observation 3:

Programm-Improvements need not always be correct :-(

Example:

```
y = f() + f();   ⟹   y = 2 * f();
```

Idea: Save the second evaluation of `f()` ???

Problem: The second evaluation may return a result different from the first; (e.g., because `f()` reads from the input :-)

Consequences:

$\Longrightarrow$ Optimizations have assumptions.

$\Longrightarrow$ The assumption must be:

- formalized,
- checked :-)

$\Longrightarrow$ It must be proven that the optimization is correct, i.e., preserves the semantics !!!

Observation 4:

Optimization techniques depend on the programming language:

- → which inefficiencies occur;
- → how analyzable programs are;
- → how difficult/impossible it is to prove correctness ...

Example: Java

Unavoidable Inefficiencies:

- $*$ Array-bound checks;
- $*$ Dynamic method invocation;
- $*$ Bombastic object organization ...

Analyzability:

- $+$ no pointer arithmetic;
- $+$ no pointer into the stack;
- $-$ dynamic class loading;
- $-$ reflection, exceptions, threads, ...

Correctness proofs:

- \+ more or less well-defined semantics;
- − features, features, features;
- − libraries with changing behavior ...

... in this course:

a simple imperative programming language with:

- variables // registers
- $R = e;$ // assignments
- $R = M[e];$ // loads
- $M[e_1] = e_2;$ // stores
- if (e) s_1 else s_2 // conditional branching
- goto $L;$ // no loops :-)

Note:

- For the beginning, we omit procedures :-)
- External procedures are taken into account through a statement $f()$ for an unknown procedure f.

  $\Longrightarrow$ intra-procedural

  $\Longrightarrow$ kind of an intermediate language in which (almost) everything can be translated.

Example: `swap()`

$$
\begin{array}{lllll}
0: & A_1 = A_0 + 1 * i; & // & A_0 == \&a \\
1: & R_1 = M[A_1]; & // & R_1 == a[i] \\
2: & A_2 = A_0 + 1 * j; & & \\
3: & R_2 = M[A_2]; & // & R_2 == a[j] \\
4: & \text{if } (R_1 > R_2) \{ & & \\
5: & \quad A_3 = A_0 + 1 * j; & & \\
6: & \quad t = M[A_3]; & & \\
7: & \quad A_4 = A_0 + 1 * j; & & \\
8: & \quad A_5 = A_0 + 1 * i; & & \\
9: & \quad R_3 = M[A_5]; & & \\
10: & \quad M[A_4] = R_3; & & \\
11: & \quad A_6 = A_0 + 1 * i; & & \\
12: & \quad M[A_6] = t; & & \\
 & \} & &
\end{array}
$$

Optimization 1: $1 * R \Longrightarrow R$

Optimization 2: Reuse of subexpressions

$$A_1 == A_5 == A_6$$
$$A_2 == A_3 == A_4$$

$$M[A_1] == M[A_5]$$
$$M[A_2] == M[A_3]$$

$$R_1 == R_3$$

By this, we obtain:

$$
\begin{array}{lcl}
A_1 & = & A_0 + i; \\
R_1 & = & M[A_1]; \\
A_2 & = & A_0 + j; \\
R_2 & = & M[A_2]; \\
\textsf{if } (R_1 > R_2) \{ & & \\
\qquad t & = & R_2; \\
\qquad M[A_2] & = & R_1; \\
\qquad M[A_1] & = & t; \\
\qquad \} & &
\end{array}
$$

Optimization 3: Contraction of chains of assignments :-)

Gain:

	before	after
$+$	6	2
$*$	6	0
load	4	2
store	2	2
$>$	1	1
$=$	6	2

1 Removing superfluous computations

1.1 Repeated computations

Idea:

If the same value is computed repeatedly, then

→ store it after the first computation;

→ replace every further computation through a look-up!

$\Longrightarrow$ Availability of expressions

$\Longrightarrow$ Memoization

Problem: Identify repeated computations!

Example:

$$
\begin{array}{lll}
 & z = 1; \\
 & y = M[17]; \\
A: & x_1 = \boxed{y+z}; \\
 & \ldots \\
B: & x_2 = \boxed{y+z};
\end{array}
$$

Note:

B is is a repeated computation of the value of $\boxed{y + z}$, if:

(1) A is always executed before B; and

(2) y and z at B have the same values as at A :-)

$\Longrightarrow$ We need:

$\rightarrow$ an operational semantics :-)

$\rightarrow$ a method which identifies at least some repeated computations ...