CSC2/455 Software Analysis and Improvement
Value Numbering

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Outline

Review

An Introduction to Code Optimization

Local Value Numbering (LVN)

Postscript
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Postscript
What we know how to do so far

- ASTs to 3-address code
- 3-address code to Basic Blocks
- Basic blocks to Control Flow Graphs
- (Tested in first assignment, out today/tomorrow)
Some Useful Background Material

- Not needed if you have CSC 2/454
- Otherwise, read Cooper and Turczon:
  - Chapter 6 ("The Procedure Abstraction")
  - Chapter 7 ("Code Shape")
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Basic Goals

- Reduce execution time ("performance")
  - Most of our time spent on this topic
- Reduce code size
  - Was hugely important, less so in the past decade or so
  - Increasingly important again (small devices, slow memory, etc.)
- Code size reduction *often* improves performance
  - Instructions that do not execute consume no time
  - Better cache behaviour
  - But not always...
Can’t programmers write fast code?

Major impediments:

▶ High-level languages
  ▶ Productivity is more important than performance (?)
  ▶ But lose control over machine

▶ Complex machines
  ▶ Out-of-order superscalar machines

▶ “Simple” machines
  ▶ Very-long instruction word (VLIW) machines
Scope of Optimization

- What should we look at to identify optimization opportunities?
- What additional information can help us?
Local optimizations

- Look at basic blocks only
- Remember:
  - If one instruction in basic block executes, *all* instructions execute
  - Can assume instructions execute one after the other
- Major limitation
  - Size/Length of basic block
Increasing the size of basic blocks

“Region” analysis

Many forms:
  ▶ Extended Basic Blocks
  ▶ Superblocks
  ▶ Hyperblocks

Basic idea, use a *trace* to build a larger basic block
  ▶ a trace is an execution path
Global optimizations

- Global means *procedure* level
  - A procedure has a single entry and exit
  - E.g. C functions
  - *not* global as in global variables
- A global analysis usually operates on a control-flow graph
- Sometimes called “intraprocedural” analysis
Interprocedural (Whole program) Optimizations

- Operates on the entire source code of a program
- Sometimes called “context-sensitive analysis”
  - Allows compiler to distinguish invocations of the same function
  - More opportunities for optimization!
- Must keep track of function calls
  - Usually, in a structure called the “call graph”
Link-time Optimization

- Traditional compiler flow
  - Program contains multiple translation units (usu. a .c file)
  - Translation unit to object (.o file)
  - Combine object files and libraries (“link”) to generate executable
  - Usually hidden by a compiler driver like gcc

- Link-time optimization is a form of whole program optimization
  - Optimization across object boundaries
  - Often necessary for languages like C++
Runtime (Dynamic) optimization

▶ Optimization while a program is running
▶ Sometimes a necessity:
  ▶ E.g., JavaScript
▶ Sometimes called Just-in-time (JIT) compilation
  ▶ because mostly associated with JIT VMs
▶ Big advantage:
  ▶ Have nearly all the information required to optimize program
▶ Big disadvantage?
Additional Information: Profiles

- Most optimizers only look at source code
- But additional information can help:
  - What is the most common direction of this branch? (see gcc’s __builtin_expect)
  - What is the most likely target of this indirect function call?
- General technique: *profile-based optimization*
  - Instrument program to generate statistics (i.e. profile)
  - Generate statistics on program run
  - Compiler recompiles code based on gathered profile
Outline

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Getting rid of redundant calculations

\[ ed = (a_0 - a_1)(a_0 - a_1) + (b_0 - b_1)(b_0 - b_1) \]

Optimized code sequence:

```
t1 = a0 - a1
 t2 = t1 * t1
 t3 = b0 - b1
 t4 = t3 * t3
 ed = t2 + t4
```
Where does this code arise?

- High-level languages
- AST to 3-address code generation rules
  - e.g. array indexing
  - \( x = A[i][j] + A[i][j+1] \)?
Array indexing example

t1 = i * dimsize(A, 1)
t2 = t1 + j
t3 = (A + t2)

t4 = i * dimsize(A, 1)
t5 = t4 + j
t6 = t5 + 1
t7 = (A + t6)

x = t3 + t7

dimsize(A, dim) is a function that returns an integer indicating the size of dimension \( dim \) of array \( A \).
Compiler structure

- Compilers rewrite and lower your code
- Can introduce significant redundancy in the process
- Logically cleaner (and simpler!) to reduce redundancy using dedicated *passes*
  - Keeps rewrites (incl. translation) simple
Value Numbering

- Value number is a local optimization
- Assigns numbers to each value in the basic block
  - Literals
  - Variables
  - $VN(x)$ is the number assigned to $x$
- Design $VN(x)$ such that:
  - $VN(x) == VN(y)$ if-and-only-if (iff) $x == y$
Example case

t1 = a0 - a1
t2 = a0 - a1
t3 = t1 * t2

t4 = b0 - b1
t5 = b0 - b1
t6 = t4 * t5

ed = t3 + t6
Example case

\[
\begin{align*}
t_1 &= a_0 - a_1 \quad \# 2 = 0 - 1 \\
t_2 &= a_0 - a_1 \quad \# 2 = 0 - 1 \\
t_3 &= t_1 \times t_2 \quad \# 3 = 2 \times 2 \\
t_4 &= b_0 - b_1 \quad \# 6 = 4 - 5 \\
t_5 &= b_0 - b_1 \quad \# 6 = 4 - 5 \\
t_6 &= t_4 \times t_5 \quad \# 7 = 6 \times 6 \\
ed &= t_3 + t_6 \quad \# 8 = 3 + 7
\end{align*}
\]

Algorithms in Figure 8.2, 8.4 of Cooper and Turczon
Why limit ourselves to basic blocks?

What would happen if we ran value numbering across basic blocks?
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References

- Chapter 8 of Cooper and Turczon
  - Up to (but not including) 8.4.2