Outline

Review

An Introduction to Code Optimization

Local Value Numbering (LVN)

Postscript
Outline

Review

An Introduction to Code Optimization

Local Value Numbering (LVN)

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 second assignment, out next week)
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")
Outline

Review

An Introduction to Code Optimization

Local Value Numbering (LVN)

Postscript
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++
Link Time Optimizers

- LLVM LTO
- GCC LTO
- These require that object files be in compiler-specific intermediate representations
  - LLVM Bitcode for LLVM
  - GIMPLE for GCC
- Nice case studies of Firefox being compiled with LTO online
  - Search for “Firefox LTO Link Time 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?
Examples of Dynamic Optimizers

- Java
  - Hotspot VM
- JavaScript
  - V8
- Python
  - PyPy
- Your-language-here
  - RPython (used to build PyPy)
  - Graal and Truffle
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 or profile-guided optimization (PGO)
  - Instrument program to generate statistics (i.e. profile)
  - Generate statistics on program run
  - Compiler recompiles code based on gathered profile
Profile-guided Optimization using GCC

gcc -fprofile-generate program.c # instrumented executable
./program # gathers profile data
gcc -fprofile-use program.c # PGO executable

- This instruments the code to gather:
  - statistics of values in expressions
  - branch probabilities
- These values are gathered ("profiled") when the program is run
- The feedback gathered during a run can be used for:
  - Inlining functions
  - Laying out code
  - Loop unrolling, etc.
Outline

Review

An Introduction to Code Optimization

Local Value Numbering (LVN)

Postscript
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:

```plaintext
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
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 (0 or 1).
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 numbering is a local optimization
- Assigns numbers to each value in the basic block
  - Literals
  - Variables
  - Expressions
  - $VN(x)$ is the number assigned to $x$
- Design $VN(x)$ such that:
  - $VN(x) == VN(y)$ if-and-only-if (iff) $x == y$
t1 = a0 - a1

\[ t2 = a0 - a1 \]

\[ t3 = t1 \times t2 \]

\[ t4 = b0 - b1 \]

\[ t5 = b0 - b1 \]

\[ t6 = t4 \times t5 \]

\[ ed = t3 + t6 \]
Example case: Assigning value numbers

\[
\begin{align*}
  t1 &= a0 - a1 & \# & 2 = 0 - 1 \\
  t2 &= a0 - a1 & \# & 2 = 0 - 1 \\
  t3 &= t1 * t2 & \# & 3 = 2 * 2 \\
  t4 &= b0 - b1 & \# & 6 = 4 - 5 \\
  t5 &= b0 - b1 & \# & 6 = 4 - 5 \\
  t6 &= t4 * t5 & \# & 7 = 6 * 6 \\
  ed &= t3 + t6 & \# & 8 = 3 + 7
\end{align*}
\]
t1 = a0 - a1  # 2 = 0 - 1

\[ t3 = t1 \times t1 \]  # 3 = 2 \times 2

\[ t4 = b0 - b1 \]  # 6 = 4 - 5

\[ t6 = t4 \times t4 \]  # 7 = 6 \times 6

\[ ed = t3 + t6 \]  # 8 = 3 + 7

Algorithms in Figure 8.2, 8.4 of Cooper and Turczon
Quality of $VN(x)$

- What happens if your $VN(x)$ assigns different values to $VN(x)$ and $VN(y)$ when $x == y$?
  - $a = 1 \times c$
  - $b = c$

- What happens if your $VN(x)$ assigns the same value to $VN(x)$ and $VN(y)$ when $x \neq y$?
  - $t1 = c + d; t2 = t1 + e$
  - $t3 = d + e; t4 = t1 + c$
  - Here: is $t2$ equal to $t4$?
  - (assume $c, d$ and $e$ are float)
Completeness and Soundness

- **Completeness**
  - Can we prove all true statements?
  - e.g., can we derive equality for all expressions that are equal?
  - False Negative, we say “no”, when it is actually “yes” [Type II error]

- **Soundness**
  - Roughly, are all statements that have proofs actually true?
  - e.g., we can never derive equality for expressions that are not equal
  - False Positive, we say “yes”, when it is actually “no” [Type I error]
Why limit ourselves to basic blocks?

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

Review

An Introduction to Code Optimization

Local Value Numbering (LVN)

Postscript
References

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