CS 536

Optimization

Roadmap

- Last time:
  - CodeGen for the remainder of AST nodes
  - Introduced the control-flow graph
- This time:
  - Optimization Overview
  - Discuss a couple of optimizations
    - Review CFGs
  - Course evaluations

Optimization Overview

Optimization Goals

- What are we trying to accomplish?
  - Traditionally, speed
  - Lower power
  - Smaller footprint
  - Bug resilience?
- The fewer instructions the better

Optimization Guarantee

- Informally: Don’t change the program’s output
  - We may relax this to “Don’t change the program’s output *on good input*”
  - This can actually be really hard to do

Optimization Difficulties

- There's no perfect way to check equivalence of two arbitrary programs
  - If there was we could use it to solve the halting problem
  - We'll attempt to perform behavior-preserving transformations

Program Analysis

- A perspective on optimization
  - Recognize some behavior in a program
  - Replace it with a “better” version
- Constantly plagued by the halting problem
  - We can only use approximate algorithms to recognize behavior

Program Behavior

- Two terms in program analysis / behavior detection:
  - Soundness: All results that are output are valid
  - Completeness: All results that are valid are output
- These terms are necessarily mutually exclusive
  - If an algorithm was sound *and* complete, it would either:
    1. Solve the halting program
    2. Detect a trivial property

Back to Optimization

- We want our optimizations to be *sound* transformations
  - In other words, they are always valid, but will miss some behaviors

You may be thinking...

- I'm sad because this makes optimization seem pretty limited

- Cheer up! Our optimization may be able to detect many *practical* instances of the behavior

Now you may be thinking...

- I’m happy because I’m guaranteed that my optimization won’t do any harm

- Settle down! Our optimization still needs to be efficient.

Or maybe you are thinking…

- I don’t know how to feel about any of this without understanding how often it comes up

What *Can* We Do?

- We can pick some low-hanging fruit

Example Optimizations

Peephole Optimization

- A naïve code generator tends to output some silly code
  - Err on the side of correctness over efficiency
- Pattern-match the most obvious problems

CFG for Program Analysis

- Consider the following sequence of instructions:

$$\text{push}\left\{\begin{array}{l}\texttt{sw \ \ \ \$t0 0(\$sp)}\\ \texttt{subu \$sp \$sp 4}\end{array}\right.$$
$$\text{pop}\left\{\begin{array}{l}\texttt{lw \ \ \ \$t0 4(\$sp)}\\ \texttt{addu \$sp \$sp 4}\end{array}\right.$$

- We'd like to remove this sequence…
  - Is it sound to do so?
  - Maybe not!

Review: the CFG

- Program as a flowchart
- Nodes are "Basic Blocks"
- Edges are control transfers
  - Fallthrough
  - Jump
  - *Maybe* function calls

CFG for Optimization

- We can limit our peephole optimizations to *intra-block* analysis
  - This ensures, by definition, that no jumps will intrude on the sequence
- We will assume for the rest of our peephole optimizations that instruction sequences are in one block

Peephole Examples

- Called “peephole” optimization because we are conceptually sliding a small window over the code, looking for small patterns

Outline

- Four different optimizations
  - Peephole optimization
  - Loop-Invariant Code Motion
  - For-loop strength reduction
  - Copy propagation

Performed *after* machine code generation

Performed *before* machine code generation

Peephole Optimization 1

- Remove no-op sequences
  - Push followed by pop
  - Add/sub 0
  - Mul/div 1

push

```
sw    $t0 0($sp)
subu $sp $sp 4
```

pop

```
lw    $t0 4($sp)
addu $sp $sp 4
```

```
addu $t1 $t1 0
```

```
mul $t2 $t2 1
```

Peephole Optimization 2

- Simplify sequences
  - Ex. Store then load
  - Strength reduction

```
sw   $t0 -8($fp)
lw   $t0 -8($fp)

mul   $t1 $t1 2

add   $t2 $t2 1
```

Useless instruction

shift-left $t1

inc $t2

Peephole Optimization 3

- Jump to next instruction

```
      j  Lab1
Lab1  …
```

Remove this instruction

LICM

- Loop Invariant Code Motion
  - Don't duplicate effort in a loop
- Goal
  - Pull code out of the loop
  - "Loop hoisting"
- Important due to "hot spots"
  - Most execution time due to small regions of deeply-nested loops

LICM: Example

```
for (i=0; i<100; i++) {
    for (j=0; j<100; j++) {
        for (k=0; k<100; k++) {
            A[i][j][k] = i*j*k
        }
    }
}
```

Sub-expression *invariant* with respect to Innermost loop

```
for (i=0; i<100; i++) {
    for (j=0; j<100; j++) {
        temp = i * j
        for (k=0; k<100; k++) {
            A[i][j][k] = temp *k
        }
    }
}
```

LICM: When Should we Do it?

- In the previous example, showed LICM on source code
- At IR level, more candidate operations
- ASM might be *too* low-level
  - Need a guarantee that the loop is *natural*
    - No jumps into the loop

```
tmp0 = FP + offsetA
for (i=0; i<100; i++){
    tmp1 = tmp0 - i*40000
    for (j=0; j<100; j++){
        tmp2 = ind2
        tmp3 = i*j
        for (k=0; k<100; k++){
            T0 = tmp3 * k
            T1 = tmp2 - k*4
            store T0, 0(T1)
        }
    }
}
```

LICM: How Should we Do it?

- Two factors, which really generalize to optimization:
  - Safety
    - Is the transformation semantics-preserving?
      - Make sure the operation is truly loop-invariant
      - Make sure ordering of events is preserved
  - Profitability
    - Is there any advantage to moving the instruction?
      - May end up doing instructions that are never executed
      - May end up performing more intermediate computation than necessary

Other Loop Optimizations

- Loop unrolling
  - For a loop with a small, constant number of iterations, we may actually save time by just placing every copy of the loop body in sequence (no jumps)
  - May also consider doing multiple iterations within the body
- Loop fusion
  - Merge two sequential, independent loops into a single loop body (fewer jumps)

Jump Optimizations

Disclaimer: Require some extra conditions

- Jump around jump

```
        beq  $t0,$t1,Lab1
        j     Lab2
Lab1:   …
        …
Lab2:   …
```

```
        bne  $t0,$t1,Lab2
Lab1:   …
        …
Lab2:   …
```

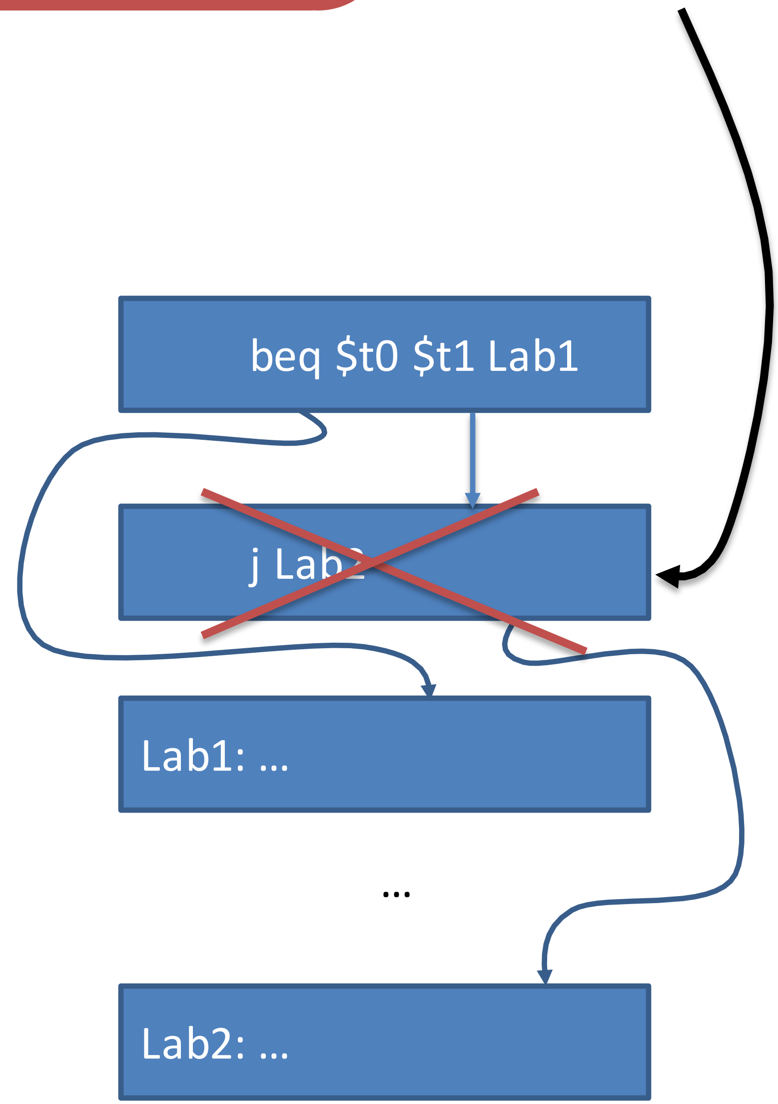
- Jump to jump

```
        j   Lab1
        …
Lab1:   j   Lab2
        …
Lab2:   …
```

```
        j   Lab2
        …
Lab1:   j   Lab2
        …
Lab2:   …
```

Intraprocedural Analysis

- The past two optimizations had some caveats
  - There may be a jump into your eliminated code
- We'd like to introduce a control-flow concept beyond basic blocks:
  - Guarantee that block1 must be executed in order to get to block2
    - This goes by a pretty boring name

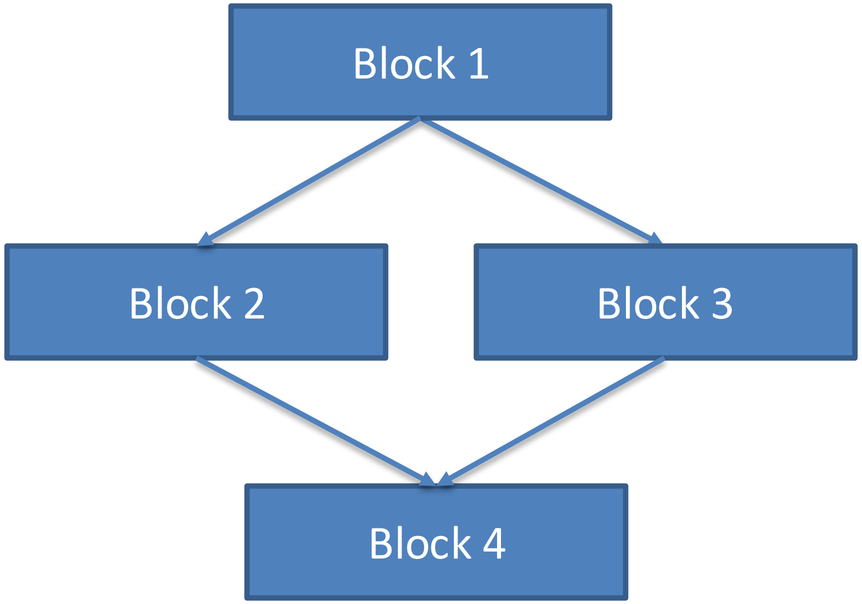



Domination

Dominators & PostDominators

- We say that block A dominates block B if A **must** be executed before B is executed
- We say that block A postdominates block B if A **must** be executed after B

Control Flow Graph



Semantics preserving?

- Do we really need semantics preserving optimizations?
- Are there examples where we don’t?

Next Time

- Wrap up optimization