CS322 Languages and Compiler Design II

Spring 2012

Lecture 11

Code Optimization

- Really "improvement" rather than "optimization;" results are seldom optimal.
- Remove inefficiencies in user code and (more importantly) in compiler-generated code.
- Can be applied at several levels, chiefly intermediate or assembly code.
- Can operate at several levels:

- **"Peephole"** : very local IR or assembly
- **"Local"** : within basic blocks
- **"Global"** : entire procedures
- **"Interprocedural"** : entire programs (maybe even multiple source files)

- Theoretical tools: graph algorithms, control and data flow analysis.
- Practical tools: few.
- **Most** of a serious modern compiler is devoted to optimization.

Peephole Optimizations

- Look at short sequences of statements (in IR or assembly code)
- Correct inefficiencies produced by excessively local code generation strategies.
- Repeat!
- Same effect can often be achieved by using smarter (but hence more complex) code generation in the first place.

Example Peephole Optimizations

- Redundant instructions

```
mov %f0, %f2
mov %f0, %f2 ; ok to remove if in same basic block
```

- Unreachable code

```
LOOP IF x > 2 THEN EXIT ELSE X := X + 1 END;

L1: IF X > 2 GOTO L2
    GOTO L3
L2: GOTO L4
    GOTO L1  ; never executed
L3: X := X + 1
    GOTO L1
L4: ...
```

- Flow-of-control fixes: remove jumps to jumps, e.g.,

```
L1: IF X > 2 GOTO L4
    X := X + 1
    GOTO L1
L4: ...
```

MORE PEEPHOLE OPTIMIZATIONS

- **Algebraic Simplification**

```
x + 0 = 0 + x = x
x - 0 = x
x * 1 = 1 * x = x
x/1 = x
```

- **Strength Reduction**

Target hardware may have cheaper ways to do certain operations.

E.g., multiplication or division by a power of 2 is better done by shifting.

```
imull $8, %l2    ⇒ sall $3, %l2
```

- Use of **machine idioms**

Target hardware may have quirks/features that make certain sequences faster:

```
imull  $8,%l2
addl   %l3,%l2
addl   $20,%l2      ⇒ leal 20(%l3,%l2,8)
```


LOCAL (BASIC BLOCK) OPTIMIZATIONS

- Typically applied to IR, **after** addressing is made explicit, but **before** machine dependencies appear.
- Most important: **Common Subexpression Elimination** (CSE)

```
i := j + 1
a[i] := a[i] + j + 1
```

Avoid duplicating the code for `j+1` or the addressing code for `a[i]`. One technique: build **directed acyclic graph** (DAG) for basic block.

- **Copy Propagation**

```
a := b + 1    ⇒   a := b + 1
c := a            c := a   ; maybe can now omit
d := c            d := a
```

- **Algebraic Identities**

E.g., use associativity and commutativity of +

```
a := b + c     ⇒  a := b + c
b := c + d + b    b := b + c + d ; now do CSE
```



```
CSE EXAMPLE                 Source: i := j + 1
                                    a[i] := b[i] + j + 1

Naive IR:               After CSE:

t1 := addr j            t1 := addr j
t2 := *t1               t2 := *t1
t3 := const 1           t3 := const 1
t4 := t2 + t3           t4 := t2 + t3   ; j + 1
t5 := addr i            t5 := addr i
*t5 := t4               *t5 := t4

t6 := addr b            t6 := addr b
t7 := addr i
t8 := *t7
t9 := const 4           t9 := const 4
t10 := t8 * t9          t10 := t4 * t9
t11 := t6 + t10         t11 := t6 + t10   ; &(b[i])
t12 := *t11             t12 := *t11
t13 := addr j
t14 := *t13
t15 := const 1
t16 := t14 + t15                          ; j + 1
t17 := t12 + t16        t17 := t12 + t4
t18 := addr a           t18 := addr a
t19 := addr i
t20 := *t19
t21 := const 4
t22 := t20 * t21
t23 := t18 + t22        t23 := t18 + t10 ; &(a[i])
*t23 := t17             *t23 := t17
```


GLOBAL (FULL PROCEDURE) OPTIMIZATION

Loop optimizations are most important.

- **Code motion**: "hoist" expensive calculations above the loop.
- Use **induction variables** and reduction in strength. Change only one index variable on each loop iteration, and choose one that's cheap to change.

Also continue to apply CSE, copy propagation, dead code elimination, etc. on global scale.

Based on **control flow graph**.

Example: Computing dot product (assuming `i,a` local; `b,c` global). Local CSE already performed within basic blocks.

```
a = 0;
for (i = 0; i < 20; i++)
  a = a + b[i] * c[i];
return a;
```

Example IR...

```
B1    t1 := const 0
      t2 := addr a
      *t2 := t1
      t3 := addr i
      *t3 := t1

B2    L2:
      t5 := addr i
      t6 := *t5
      t7 := const 20
      if t6 >= t7 goto L4

B3    t8 := addr a
      t9 := *t8
      t10 := addr b
      t11 := addr i
      t12 := *t11
      t13 := const 4
      t14 := t12 * t13
      t15 := t10 + t14 ; &(b[i])
      t16 := *t15
      t17 := addr c
      t18 := t17 + t14 ; &(c[i])
      t19 := *t18
      t20 := t16 * t19              B4    L4:
      t21 := t9 + t20                     t24 := addr a
      *t8 := t21                          t25 := *t24
      t22 := const 1                      return t25
      t23 := t12 + t22
      *t11 := t23
      goto L2
```


Example: Effects of Global Optimization

- Promote locals `a` and `i` to registers.
- Induction variable: replace `i` with `i*4`, thus reducing strength of per-loop operation; adjust test accordingly.
- Hoist all constants out of loop.

Results on example:

```
B1    t1 := const 0                   t1 := const 0
      t2 := addr a
      *t2 := t1                       t9 := t1   ; a
      t3 := addr i
      *t3 := t1                       t6 := t1   ; i * 4
                                      t13 := const 4
                                      t7 := const 80
                                      t8 := addr a
                                      t10 := addr b
                                      t17 := addr c
```



```
B2    L2:                             L2:
      t5 := addr i
      t6 := *t5
      t7 := const 20
      if t6 >= t7 goto L4             if t6 >= t7 goto L4

B3    t8 := addr a
      t9 := *t8
      t10 := addr b
      t11 := addr i
      t12 := *t11
      t13 := const 4
      t14 := t12 * t13
      t15 := t10 + t14                t15 := t10 + t6
      t16 := *t15                     t16 := *t15
      t17 := addr c
      t18 := t17 + t14                t18 := t17 + t6
      t19 := *t18                     t19 := *t18
      t20 := t16 * t19                t20 := t16 * t19
      t21 := t9 + t20                 t9 := t9 + t20
      *t8 := t21
      t22 := const 1
      t23 := t12 + t22                t6 := t6 + t13
      *t11 := t23
      goto L2                         goto L2

B4    L4:                             L4:
      t24 := addr a
      t25 := *t24
      return t25                      return t9
```


Interprocedural Optimization

Procedure inlining is most important.

- Replace a procedure call with a copy of the procedure body (including initial assignments to parameters).
- Applicable when body is not too big, or is called only once.

Benefits:

- Saves overhead of procedure entry/exit, argument passing, etc.
- Permits other optimizations to work over procedure boundaries.
- Particularly useful for languages that encourage use of small procedures (e.g. OO state get/set methods).

Cost:

- Risk of "code explosion."
- Doesn't work when callee is not statically known (e.g. OO dynamic dispatch or FP first-class calls).