COMS W4115
Programming Languages and Translators
Lecture 24: Code Optimization
April 21, 2014

Lecture Outline

1. Code optimization strategies
2. Peephole optimization
3. Common subexpression elimination
4. Copy propagation
5. Dead-code elimination
6. Code motion
7. Induction variables and reduction in strength

1. Code Optimization Strategies

- We can try to improve the performance of the target program by performing code-improving transformations within basic blocks. This approach is called *local optimization*.
- A more thorough, more global job of code optimization can be done by looking at transformations across the basic blocks of a procedure, a task sometimes called *intra-procedural optimization*.
- We can also look at *inter-procedural optimization* where we try to improve the performance of a program as a whole.
- The general strategy for code optimization is to look for program transformations that give the most bang for the buck: they should be easy to implement, they should not take too much compilation time, and they should have high payoff. As with many tasks in compilation, code optimization is a study in tradeoffs.

2. Peephole Optimization

- One strategy for generating good code is to first use a naive code generation algorithm and then apply local improvements to the code by examining a sliding window of instructions, called the *peephole*, and replacing an instruction sequence within the peephole by shorter or faster sequence of code. Here are some typical peephole transformations:
- Eliminating redundant loads and stores
  - In the instruction sequence
    ```
    LD R0, a
    ST a, R0
    ```
    the store instruction is redundant and can be eliminated.

- Eliminating unreachable code
  - In the instruction sequence

```
L1: goto L2
    x = y + z
L2: a = b + c
```

    the second statement is unreachable and can be eliminated.

- Eliminating unnecessary jumps
  - In the instruction sequence

```
L1: if x < y goto L2
    ...
L2: goto L3
```

    the jump to a jump can be replaced by

```
L1: if x < y goto L3
    ...
L2: goto L3
```

- Algebraic simplification
  - Three-address statements such as

    `x = x + 0` or `x = x * 1`

    where `x` is an integer can be eliminated entirely.

- Reduction in strength
  - An expensive operation such as x^2 can be replaced by a cheaper operation such as `x * x`.

3. Common Subexpression Elimination

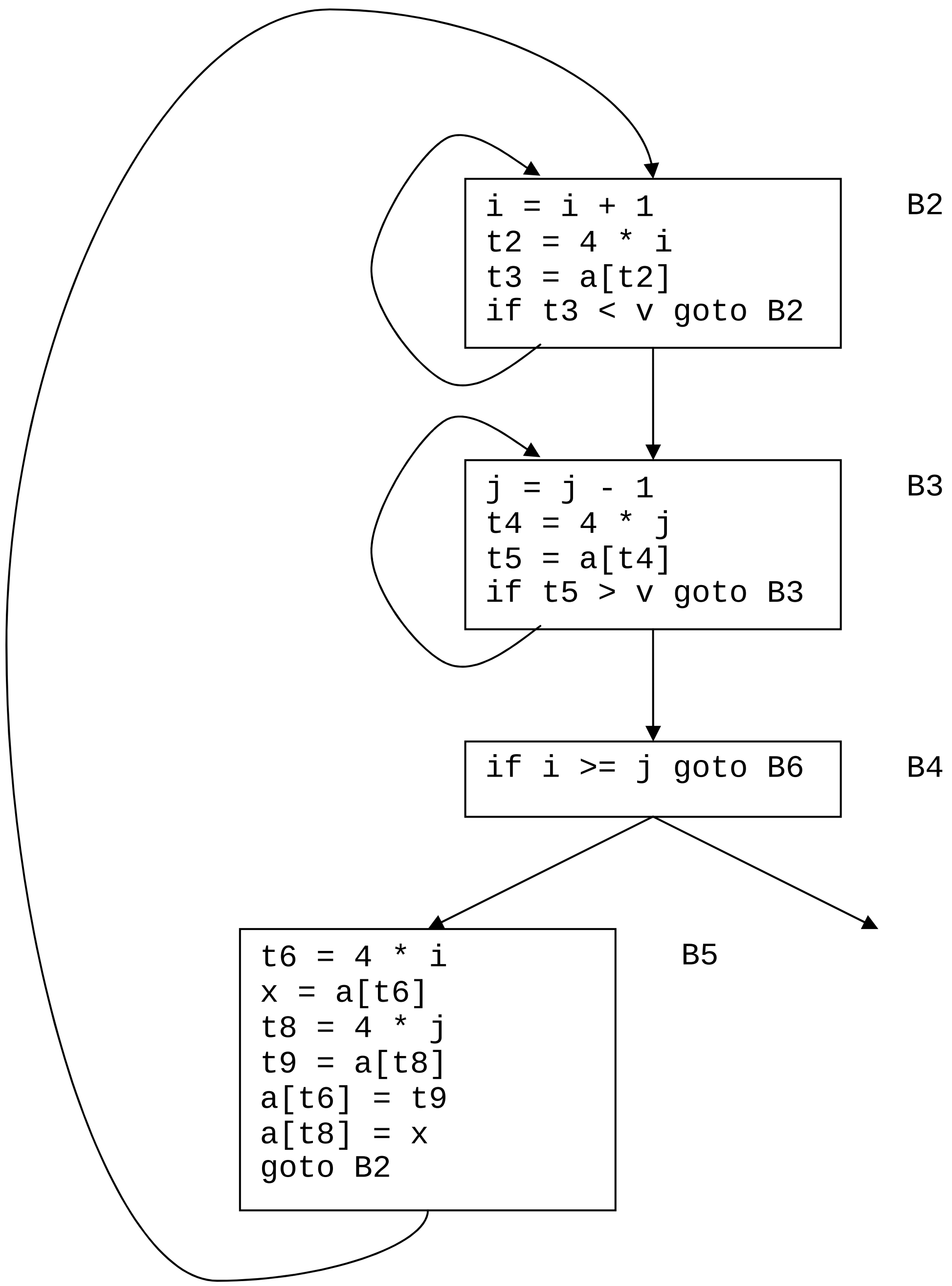
- Local common subexpression elimination

  - In the following `BEFORE` basic block, the assignments to `t7` and `t10` compute the subexpressions `4 * i` and `4 * j`, which have been eliminated in the `AFTER` block by local common subexpression elimination:

```
  BEFORE                    AFTER
t6 = 4 * i                t6 = 4 * i
x = a[t6]                 x = a[t6]
t7 = 4 * i
t8 = 4 * j                t8 = 4 * j
t9 = a[t8]                t9 = a[t8]
a[t7] = t9                a[t6] = t9
t10 = 4 * j
a[t10] = x                a[t8] = x
goto B2                   goto B2
```

- Global common subexpression elimination

    - In the following flow graph, block `B5` computes the common subexpressions `4 * i` and `4 * j`, which are computed in blocks `B2` and `B3`, respectively.



    - Notice that block `B5` can be replaced by the following block since block `B2` has computed `4*i` into `t2` and `a[t2]` into `t3`:

```
x = t3
t8 = 4 * j
t9 = a[t8]
a[t2] = t9
a[t8] = x
goto B2
```

- This block can be replaced by following block by noticing that block `B3` has computed `4*j` into `t4` and `a[t4]` into `t5`:

```
x = t3
t9 = a[t4]
a[t2] = t9
a[t4] = x
goto B2
```

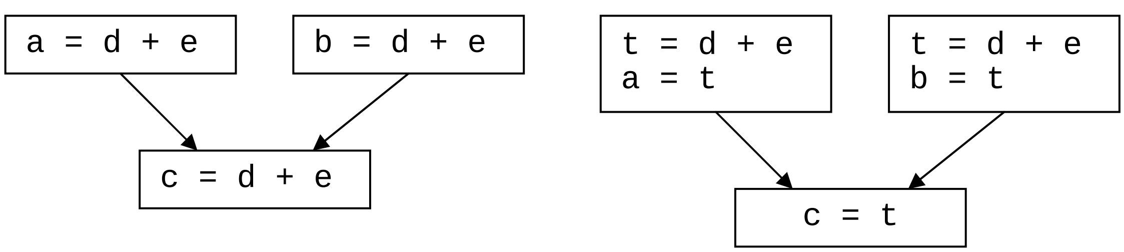
- We now notice that block `B3` has already computed `a[t4]` into `t5` so we can replace the second and third statements by the assignment `a[t2] = t5` to obtain the following optimized block:

```
x = t3
a[t2] = t5
a[t4] = x
goto B2
```

So far we have reduced the original nine-statement block `B5` into a four-statement block.

4. Copy Propagation

- A three-address statement of the form `u = v` is called a *copy statement*, or *copy* for short.
- We can introduce copy statements to avoid recomputing common subexpressions:



5. Dead-Code Elimination

- Statements that compute values that never get subsequently used can be eliminated.
- Often copy propagation turns copy statements into dead code.
- Consider the reduced basic block for `B5`:

```
x = t3
a[t2] = t5
a[t4] = x
goto B2
```

After copy propagation this block becomes:

```
x = t3
a[t2] = t5
a[t4] = t3
goto B2
```

We now observe `x` is never used so the first statement can be eliminated. The block now becomes

```
a[t2] = t5
a[t4] = x
goto B2
```

6. Code Motion

- Loop-invariant computations are best moved outside loops.
- Consider the while-statement:

```
while (i <= limit – 2)
```

Code motion will produce a faster equivalent loop when the limit computation is performed once before entering the loop:

```
t = limit – 2
while (i <= t)
```

7. Induction Variables

- A variable x is an *induction variable* if its value always changes by a constant whenever it is assigned a new value.

- o For example, `i` and `t2` are induction variables in block `B2` of the flow graph in Section 3 above.

- Reduction in strength and induction-variable elimination can be used to speed up loops. See ALSU, Figs. 9.8 – 9.10, pp. 592-595 for an extended example.

8. Practice Problems

1) ALSU, Exercise 9.1.1 (p. 596).
2) ALSU, Exercise 9.1.4 (p. 596).

9. Reading

- ALSU, Sections 8.5, 8.7, 9.1

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