Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

6.035, Fall 2000 — Segment V: Data Flow Optimization — Homework Assignment — Wednesday, November 8

DUE: Wednesday, November 15

1. **Conservative Analysis**

   When estimating each of the following sets in a data-flow analysis for the specified optimization, tell whether too-large or too-small estimates are conservative. Explain your answer in terms of the intended use of the information.

   (a) Available expressions, to be used in common-subexpression elimination (CSE).

   (b) Variables changed by a procedure, to be used for CSE and copy propagation.

   (c) Variables not changed by a procedure, also for CSE and copy propagation.

   (d) Copy statements (such as `x = y`) reaching a given point, for use in copy propagation.

2. **Manual Optimization**

   For the basic block:

```
a = 7
b = 11
c = 13
d = a + x
e = b + c
f = e
g = f
g = d + y
a = b + c
```

   Show the results of each of the following optimizations (performed separately):

   - Constant Propagation/Folding.

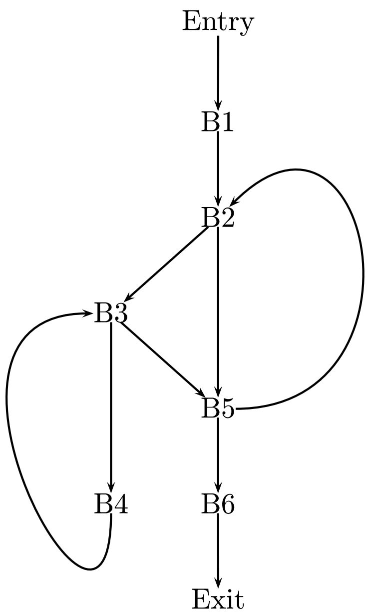
   - Copy Propagation.

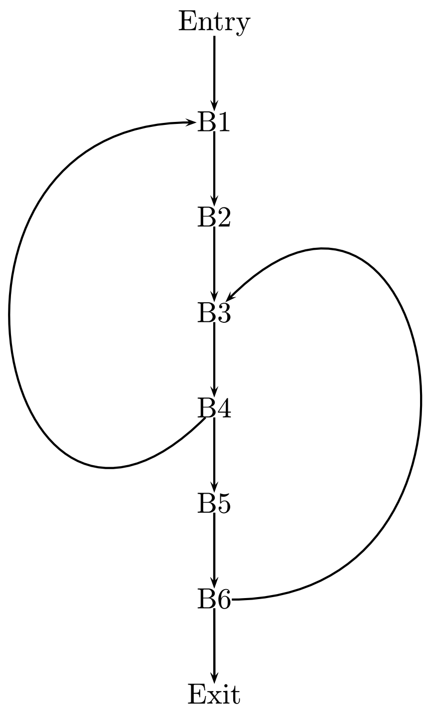
   - Common Subexpression Elimination.

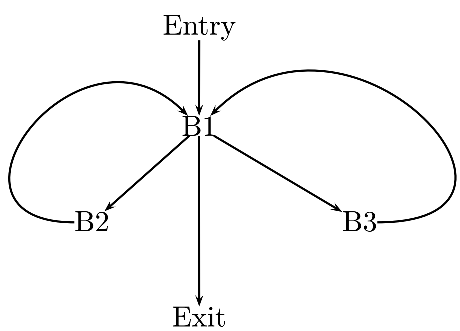
   - Dead Code Elimination (Assume that all variables are live at the end of the block).

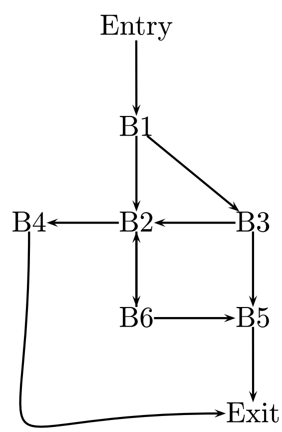
3. **Control flow graphs**

For each of the following control flow graphs, draw the dominator tree, identify all natural loops (giving the back edge, the loop header, and the set of nodes in the loop), and state whether the graph is reducible [1].









[1] Reminder: A graph is reducible iff the edge set can be divided into (1) a DAG of forward edges through which all nodes are reachable and (2) a set of back edges, where the head of each edge dominates the tail.

4. **Value Flow Analysis**

Value Flow Analysis calculates, for each variable and at each program point, the set of variables whose values have been used in computing its value. There are two flavors of Value Flow Analysis: one determines which variables *may* have been used, and the other determines which variables *must* have been used.

The data for this analysis may be represented at each point by a square matrix of bits, labeled by the variables on both sides:

	a	b	c
a			
b			
c			

Variables affected are on the left; variables used are across the top.

Where answers vary for the two flavors of Value Flow Analysis, give answers for both.

(a) Is Value Flow Analysis a forward or backward dataflow problem?

(b) What are the initialization conditions? (The initial values of IN or OUT where appropriate)

(c) What is the confluence operator?

(d) What are the GEN and KILL sets for the basic blocks in Figure 1?

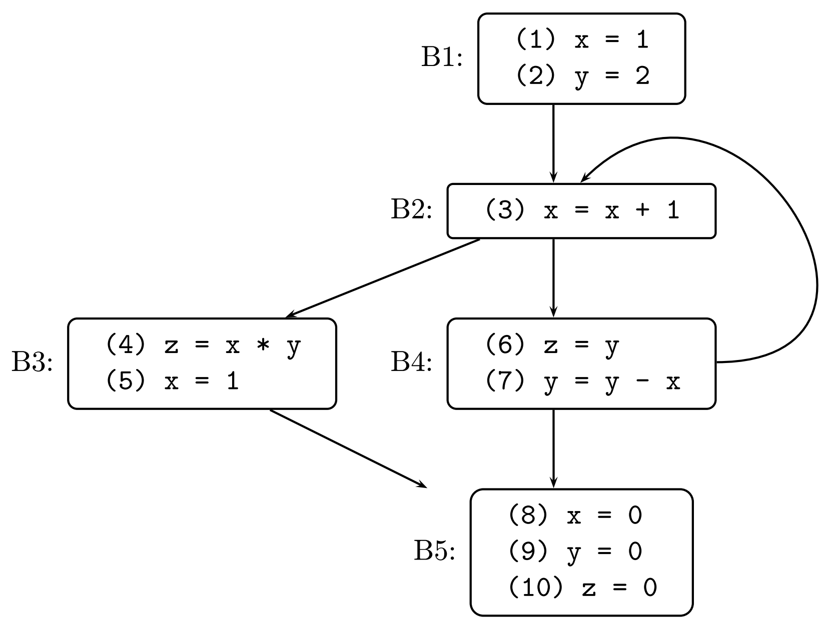


Figure 1: Problem 4 program

5. **Dataflow and lattices**

Tammy Tokentoter has come up with a new analysis. It resembles reaching definition analysis in that the analysis produces, for each program point, a bitvector with one position for each definition in the program. The operator at join points in the graph is bitwise OR, and the GEN of each basic block is a bitvector with a 1 in position i if the block contains definition i. But the transfer function is different:

OUT[b] = IN[b] XOR GEN[b]

Assume that there are n definitions in a program under analysis.

(a) Is this a legal dataflow analysis? If so, prove that the lattice and flow functions have the required properties; if not, demonstrate the property that is violated.

(b) What are the least upper bound, greatest lower bound, and order for the bitvector lattice?

(c) How many lines are connected to each lattice element in the Hasse diagram of this lattice?

6. **Lattices**

This problem deals with alleged lattices whose elements are top, bottom, and the natural numbers (0,1,2,...). You should assume that top is always greater than all of the natural numbers, bottom is always less than all of the natural numbers, and that the orders defined below are only for the natural numbers themselves.

For each alleged lattice, either verify that it is a lattice or explain why it is not. If it is a lattice, specify whether it has the ascending chain property or not.

Notation: $\sqsubseteq$ is the partial ordering operator on lattice elements, while $\leq$ is the usual ordering operator on numbers.

(a) $a \sqsubseteq b$ if $a = b$

(b) $a \sqsubseteq b$ if $(a + b) \bmod 2 = 0$

(c) $a \sqsubseteq b$ if a bitwise or $b = b$

(d) $a \sqsubseteq b$ if a bitwise xor $b = b$

(e) $a \sqsubseteq b$ if $(a + b) \bmod 2 = 0$ and $a \leq b$

7. **Textbook survey**

The publisher of the textbook that we are using for the course has requested that we give you a survey about the book. Please fill it in. This is counted as part of the problem set and points will be deducted if no effort is made to answer it.

The survey is structured to be answered chapter-by-chapter; please try to give answers for all the chapters you have read, but certainly feel free to ignore questions about chapters you didn't read or exercises you didn't try.

Other opinions, such as "I've been reading the Dragon book/Appel book/lecture notes instead of the text because ..." are also welcome.

Chapter:

(a) How would you rate this chapter?
   i. Too easy, had material before
   ii. Too easy, explanations obvious
   iii. Easy because well explained
   iv. Challenging, but not too difficult
   v. Too Hard

(b) Did the authors define the new terms they used in this chapter? (Pick the best answer).
   i. Yes, all or most new terms were defined.
   ii. Sometimes new terms were not defined very well.
   iii. No, the new terms were often unexplained or unclear to me.

(c) Overall, did you find the writing to be: (Pick the best answer)
   i. very interesting
   ii. mostly interesting
   iii. uninteresting
   iv. very dull

(d) Please explain why you rated the writing as you did in Question 3?

(e) Are any subjects too lightly or too heavily covered? Are there any glaring omissions? Are the illustrations adequate, or can you suggest material that would be improved by illustrations? If you have specific suggestions about how material is presented or illustrated, please feel free to give as much detail as necessary.

(f) What sections did you find easiest to understand?

(g) What was the most interesting thing you learned in this chapter? Why?

(h) What were the most difficult or confusing topics for you in this chapter? What could the authors do to make the topic clearer? (For example, was there a particular sentence or paragraph that confused you? Would photos or diagrams help clarify the topic?) Other comments or suggestions are welcome. Please give us specific pages to refer to.

(i) Which exercises were you assigned?

(j) Which exercise taught you the most?

(k) Which exercise did you find to be too difficult, or too easy?