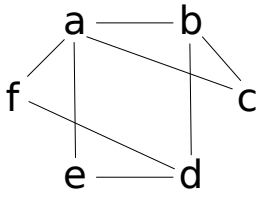
Homework 6
CS 4481

1. Consider static single-assignment (SSA) form. Consult sections 5.4.2 and 13.4.1 of the textbook for your answers.
   (a) (4 points) What does the ϕ-function do?
   (b) (3 points) What role does the ϕ-function have in making the form "single-assignment?"
   (c) (3 points) Why is SSA useful in global register allocation?

2. Consider the following interference graph:



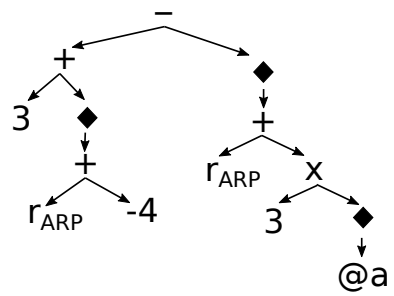
Let the number of available registers be 3, and let the spill costs be as follows:

live range	cost
a	3
b	8
c	7
d	4
e	2
f	9

   (a) (5 points) Give the order we'll color the graph using top-down coloring.
   (b) (5 points) Give the order we'll color the graph using bottom-up coloring. Use a table similar to what we used in class. Show your work. If you can choose more than one node at a given step, choose the one with the greatest cost. *Note:* bottom-up doesn't normally have a spill metric to break ties, but I'm adding one to make grading easier.

3. (10 points) Construct an abstract syntax tree for the expression `a x 2 + c x 3` where `a` is stored -4 bytes from r_{ARP} and `c` is stored 8 bytes from r_{ARP}. Your AST should include indirection operators. See pages 607-609 of the textbook.

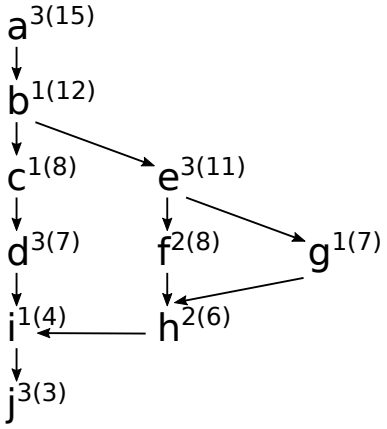
4. (10 points) Write the following AST in prefix form (see section 11.4 of the textbook).



5. (10 points) Tile the following AST (given in prefix form) using rules given in Figure 11.4 of the textbook. At each step give the production rule used to do the reduction and give the new prefix form. Write justification for any decisions made in abmiguous situations. The term r_0 refers to register r_0.

+(⧫(+(r_{ARP},4)),×(18,-(r_0,4)))

6. Consider the following dependence graph, where each node is labeled with its single instruction delay and path delay in parentheses:



   (a) (2 points) What is the critical path?

   (b) (2 points) What is the minimum number of cycles that would be required if we had a single functional unit?

   (c) (5 points) Run list scheduling using a table like we used in class to determine an improved order of instruction executions. Assume we have an infinite number of functional units. Write down the table and also the new ordering.

   (d) (1 point) Is the list-scheduled ordering optimal? How do you know?

7. (10 points) Consider the following instructions:

```
a lw $r0, 4($sp)
b addi $r1, $r0, 3
c addi $r2, $r1, 9
d lw $r3, -8($r2)
e lw $r4, 12($r1)
f mult $r5, $r4, $r1
g addi $r6, $r4, 2
h mult $r7, $r5, $r6
i add $r8, $r3, $r7
j sw $r8, 4($sp)
```

   Draw the dependence graph, using the same form as the previous problem. Each node in the graph should include the instruction's delay and path delay (number of cycles to execute that path to completion). Loads and stores take 3 cycles, adds take 1 and multiplies take 2 cycles.