# Homework 6 solution

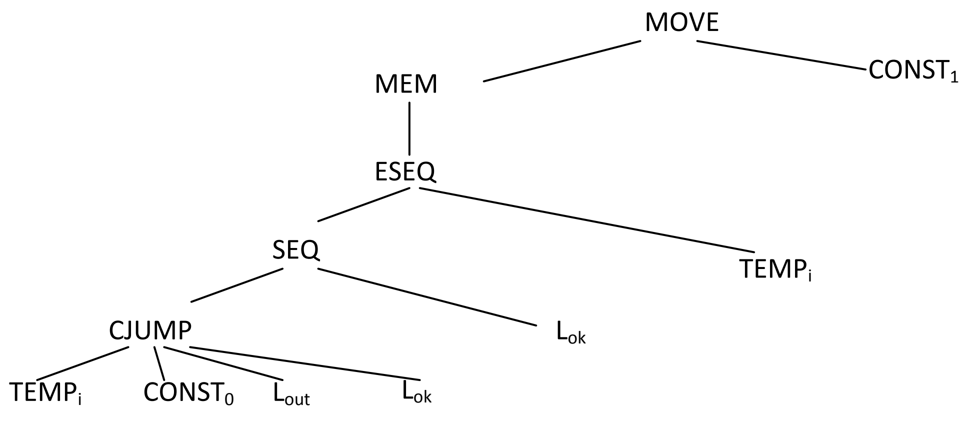
(35 pts) Translation IR into machine code.

a. (5p) Textbook 8.1 b
b. (5p) Textbook 8.1 c
c. (10p) Textbook 8.2 a
d. (10p) Textbook 8.6
e. (5p) Generate a set of traces for the basic blocks in d. You only need to represent the traces in basic block ids.

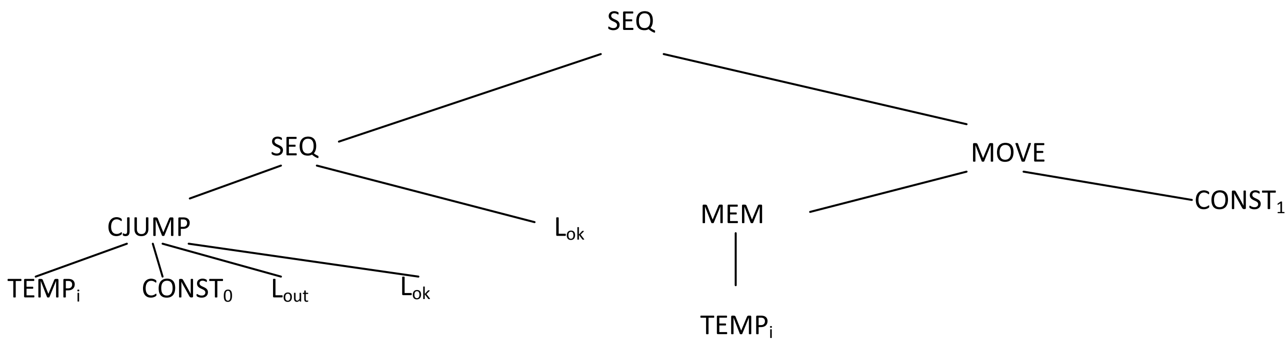
a. MOVE(MEM(ESEQ($s$, $e_1$)), $e_2$)=> SEQ (s,  MOVE (MEM(e1), e2)

b. MOVE(MEM($e_1$), ESEQ($s$, $e_2$)) ⇒ SEQ (MOVE(t, e1), SEQ(s, MOVE(MEM(t), e2)))

c. MOVE(MEM(ESEQ(SEQ(CJUMP(LT, $TEMP_i$, $CONST_0$, $L_{out}$, $L_{ok}$), $LABEL_{ok}$) $TEMP_i$)), $CONST_1$)




The result is




d.

1. $m \leftarrow 0$
2. $v \leftarrow 0$

3. if $v \geq n$ goto 15

4. $r \leftarrow v$
5. $s \leftarrow 0$

6. if $r < n$ goto 9

7. $v \leftarrow v + 1$
8. goto 3

9. $x \leftarrow M[r]$
10. $s \leftarrow s + x$
11. if $s < m$ goto 13

12. $m \leftarrow s$

13. $r \leftarrow r + 1$
14. goto 6

15. return $m$

Another solution is to break the conditional statements such as 3, 6, 11 to two basic blocks each. In such a case, the statement “goto 15” is considered as the true branch. In the above solution, statement 15 is essentially considered as the true branch, instead of the goto statement.

e.

I use the first statement id to represent the basic block

traces: 1 3 15

4 6 9 13

7

12

(15 pts) Instruction Selection

a. (10p) Textbook 9.1.
b. (5p) Prove that the maximal munch algorithm produces an optimal solution (hint: through contradiction).

**a.** **9.1 (a)** Figure omitted.

Sequence of Instructions Generated
R1 <- M[x+0]
R2 <- R1 + 1000
R4 <- R2 + fp
M[R4+0] <- R0

**(b)** Figure omitted.

R1<-M[R0+100]
R2<-R0+5
R3<-R2*R1

**b.** Assume the solution produced by the maximal munch algorithm is not optimal, meaning there are two adjacent tiles that can be combined into a single tile with lower cost. Let the roots of the two adjacent tiles are r1 and r2 and the root of the combined tile is r1. Then the maximal munch algorithm should have chosen the combined tile. The contradictions indicates the maximal munch algorithm is optimal.

(50pts) Register Allocation

a. (20p) Liveness analysis Exercise 10.1 in the textbook. For Question 10.1(c), please work directly based on the definition of interference (two variable's live ranges overlapping), instead of using the two-step algorithm on Page 214.
b. (20p) Exercise 11.1 in the textbook **(postponed)**
c. (10p) Exercises 11.2 (a) in the textbook **(postponed)**

a. 10.1 (a) arrows omitted where obvious [5p]

```
1. m ← 0
2. v ← 0

--> 3. if v>= n goto 15   ---------------------------
|              |                                     |
|              V                                     |
|          4. r ← v                                  |
|          5. s ← 0                                  |
|  --->   6. if r < n goto 9    -------------        |
| |       |                                 |        |
| |       V                                 |        |
| |   7. v ← v + 1                          |        |
|--|- 8. goto 3                             |        |
  |                                         |        |
  |       9. x ←M[r]      ←-----------------         |
  |      10. s ← s + x                               |
  |      11. if s <= m goto 13    -----              |
  |          |                        |              |
  |          v                        |              |
  |      12. m ← s                    |              |
  |      13. r ← r_ + 1    ←---------                |
  \ --   14. goto 6                                  |
|
15. return m    ←-------------------------------------
```

(b). Another way to present the solution is to directly mark the changes on the control flow edges as done in the class. But you need to show the transitions from an empty set to the final result. [10p]

| | | | Iteration 1 | | Iteration 2 | | Iteration 3 same as Iter 2 |
|---|---|---|---|---|---|---|---|
| Line | Use | Def | In | Out | In | Out | |
| 15 | m | | m | | m | | |
| 14 | | | | | r,s,n,m,v | r,s,n,m,v | |
| 13 | r | r | r | | r,n,s,m,v | r,s,n,m,v | |
| 12 | s | m | s,r | r | s,r,n,v | r,n,s,m,v | |
| 11 | s,m | | s,m,r | s,r | r,n,s,m,v | r,n,s,v,m | |
| 10 | s,x | s | s,x,m,r | s,m,r | s,x,r,n,m,v | s,r,n,m,v | |
| 9 | r | x | r,s,m | s,x,m,r | r,n,s,m,v | s,x,r,n,m,v | |
| 8 | | | | | v,n,m | v,n,m | |
| 7 | v | v | v | | v.n,m | v,n,m | |
| 6 | r,n | | r,n,s,m,v | r,s,m,v | r,n,s,m,v | r,n,s,m,v | |
| 5 | | s | r,n,m,v | r,n,s,m,v | r,n,m,v | r,n,s,m,v | |
| 4 | v | r | v,n,m | r,n,m,v | n,m,v | r,n,m,v | |
| 3 | v,n | | v,n,m | v,n,m | n,m,v | n,m,v | |
| 2 | | v | n,m | v,n,m | n,m | n,m,v | |
| 1 | | m | n | n,m | n | n,m | |

(c) Figure 3: Interference graph (5 pts)

(Omitted) Hint: draw an edge between two variables if they appear in the same In set, e.g. there's an edge between each pair from r,x,s,n,m,v.