

1) (POINTS 16/40)

Consider the following snippet of code running on 4-ways out-of-order superscalar processor. Initially, all registers contain zero.

```
lab1:  LW   R2, 0(R1)
        ADDI R2, R2, 1
        MUL  R4, R2, R2
        SW   R4, 0(R1)
        ADDI R1, R1, 4
        BNE  R2, R0, lab1
```

Working hypothesis:

- * the fetch, decode and commit stages are 4 instructions wide
- * the instruction window has 10 slots
- * we have 18 physical registers in the free pool
- * the reorder buffer has unlimited size
- * the integer multiplier has 4 stages
- * the load/store queues have 3 slots each and a common effective-address calculation unit
- * there are 2 ALUs for arithmetic and logic operations and for branching
- * an ALU performs its operation in the same cycle when the operation is issued
- * reads require 1 clock cycle (after the addressing phase)
- * the register file has 4 input- and 4 output-ports
- * there are 9 logical registers (including R0 which is hardwired to 0)
- * the store operation leaves the issue stage as it is inserted in the store queue

In order to calculate the total cycles needed to execute 3 iterations of the above loop on such machine, complete the following chart until the end of the third iteration of the code fragment above, including the renamed stream the precise evolution of the free pool of the physical registers (the register map), the Instruction Window, the Reorder Buffer (ROB) and the Load Queue (LQ) and Store Queue (SQ). Calculate the total cycles needed to execute three iterations of the above loop on such machine.

2) (POINTS 6/40) Consider the following program, assuming that A and B are variables in memory initialized to 0, and R1, R2, and R3 are registers:

```
P1    P2    P3
A=1   R1=A   R2=B
        B=1   R3=A
```

Executions of this program can be characterized by the values returned by the loads at the end of its execution, i.e., by the values of R1, R2, and R3 at the end of execution.

Using these register values, list the executions (if any) that are

- (a1) *not* coherent;
- (a2) *not* sequentially consistent;
- (a3) *not* TSO;
- (a4) *not* weakly ordered.

In each case give a justification for your answer.

3) (POINT 6/40) Answer the same questions as in (2) for the following program:

```
P1    P2
A=1   B=1
R1=B  R2=A
```

4) (POINT 6/40) Answer the same questions as in (2) for the following program:

```
P1    P2
A=1   B=1
R1=A  R3=B
R2=B  R4=A
```

5) (POINT 6/40) Answer the same questions as in (2) for the following program:

```
P1    P2
A=1   B=1
C=1   C=2
R1=C  R3=C
R2=B  R4=A
```