Section:

Name: **Email:**

Assume you have the following sequence of instructions:
or r1, r2, r3
or r2, r1, r4
or r1, r1, r2

Assume the following cycle times for each of the options related to forwarding:

Without forwarding	With Full Forwarding	With ALU-ALU Forwarding only
180ps	240	210

1. Assume there is no forwarding in the pipelined processor. Indicate hazards and add *nop* instructions if needed to eliminate them. (2 point)

Instruction sequence	
OR R1,R2,R3	
NOP	Delay I2 to avoid RAW hazard on R1 from I1
NOP	
OR R2,R1,R4	Delay I3 to avoid RAW hazard on R2 from I2
NOP	
NOP	
OR R1,R1,R2	

2. Assume there is full forwarding. Indicate hazards and add *nop* instructions if needed to eliminate them. (2 point)

Instruction sequence	
OR R1,R2,R3	
OR R2,R1,R4	No RAW hazard on R1 from I1 (forwarded)
OR R1,R1,R2	No RAW hazard on R2 from I2 (forwarded)

3. Add nop instructions to this code to eliminate hazards if there is ALU-ALU forwarding only (no forwarding from the MEM to the EX stage). (1 point)

With ALU-ALU-only forwarding, an ALU instruction can forward to the next instruction, but not to the second-next instruction (because that would be forwarding from MEM to EX). A load cannot forward at all, because it determines the data value in MEM stage, when it is too late for ALU-ALU forwarding. We have:

Instruction sequence	
OR R1,R2,R3	
OR R2,R1,R4	ALU-ALU forwarding of R1 from I1
NOP	
NOP	
OR R1,R1,R2	

4. What is the total execution time of this instruction sequence without forwarding and with full forwarding? What is the speedup achieved by adding full forwarding to a pipeline that had no forwarding? (2 point)

The total execution time is the clock cycle time times the number of cycles. Without any stalls, a three-instruction sequence executes in 7 cycles (5 to complete the first instruction, then one per instruction). The execution without forwarding must add a stall for every NOP, and execution forwarding must add a stall cycle for every NOP. Overall, we get:

No forwarding	With full forwarding	Speedup due to forwarding
(7 + 4)*180 ps = 1980 ps	7*240 ps = 1680 ps	1.18

5. What is the total execution time of this instruction sequence with only ALU-ALU forwarding? What is the speedup over a no forwarding pipeline? (2 point)

No forwarding	With ALU-ALU forwarding only	Speedup with ALU-ALU forwarding
(7 + 4)*180 ps = 1980 ps	(7+1)*210 ps = 1680 ps	1.18