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Question: Use the following code segment:

```

loop: LW      R1, 0(R2)
      ADDI1   R1, R1, 1
      SW      R1, 0(R2)
      ADDI2   R2, R2, 4
      SUB     R4, R3, R2
      BNEZ    R4, loop
    
```

RAW 2 stalls →
RAW →
RAW →
flush →

$R_1 = R_1 + 1 \rightarrow$
 $R_2 = R_2 + 4$
 $R_4 = (R_2 + 396) - (R_2 + 4) = 392 \neq 0$
 $99 - 99 = 0$

Assume that the initial value of R3 is R2+396.

- Show the timing of this instruction sequence for the mips pipeline without any forwarding but assuming a register read and a write in the same clock cycle. Assume that a branch is handled by flushing the pipeline. What is the CPI? How many total cycles does it take to execute the loop?
- Repeat with normal forwarding hardware. Assume that the branch is handled by predicting it as Not Taken and resolved in the ID stage?
- Repeat b assuming the pipeline with a one-cycle delayed branch and forwarding hardware. You may reorder the instructions.

Solution:

a

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
LW	IF	ID	EX	MEM	WB														
ADDI1		IF	EX	MEM	WB	X	M	W											
SW					IF	S	S	D	X	M	W								
ADDI2								IF	ID	EX	MEM	WB							
SUB									IF	S	S	ID	EX	MEM	WB				
BNEZ												IF	S	S	ID	EX	MEM	WB	
LW																IF	ID	EX	MEM

*IF Branch is resolved @ the MEM stage
 ⇒ One loop takes 17 cycles ⇒ $CPI = \frac{17}{6} = 1 + \frac{11}{6} = 2.83$
 Total # of cycles = $98 \times 17 + 18 = 1684$
 ↑
 Last loop Not taken

Loop cycles = 6 + (2 RAW stalls + one flush since Branch is taken)
 = 9
 $\Rightarrow CPI = 1 + \frac{3}{6} = 1.5$
 Total cycles = $98 \times 9 + (\text{last loop}) = 98 \times 9 + 12 = 894$ cycles.

(b)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
LW	IF	ID	EX	ME	WB														
ADD1		IF	ID	S	EX	M	WB												
SW			F	S	D	EX	M	WB											
ADD2					F	D	X	M	WB										
SUB						F	D	X	M	WB									
BNEZ							F	S	D	X	M	W							
?								F	S	S	S	S							

additional 3 cycles for last loop (not taken).
 one flushed

Predict NOT Taken
 so, incorrect instruction is fetched.
 MUST flush since Branch is Taken.
 then LW

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
LW	IF	ID	EX	ME	WB														
ADD1		IF	D	EX	M	WB													
SW			IF	D	EX	M	W												
ADD2				F	D	X	M	W											
SUB					F	D	X	M	W										
BNEZ						F	D	X	M	W									
SW						F	D	X	M	W									
2nd LW							F												

3 pts for re-order
 ADD1 → 1
 LW → 2
 BNEZ → 3
 SUB → 4

Loop cycles = 6 $\Rightarrow CPI = \frac{6}{6} = 1 = 1 + \frac{0}{6} \text{ stalls} = 1.0$
 total cycles = $98 \times 6 + 10 = 598$ cycles!

If the prediction is taken, then we do not need to flush after the branch. The loop takes 8 cycles. 2nd LW starts at cycle 9. ...
 $CPI = 1 + \frac{2}{6}$

$R_3 = R_3 + 196 \Rightarrow 49$ loops
 (a) Total cycles = $48 \times 17 + 18 = 834$
 $= 48 \times 9 + 12 = 444$
 (b) $= 48 \times 6 + 10 = 298$
 (c)