

### Question 1. (20%)

Consider two different implementations of the same instruction set architecture. The instructions can be divided into three classes according to their CPI (classes A, B, and C). P1 with a clock rate of 2.5 GHz and CPIs of 1, 2 and 3, and P2 with a clock rate of 2 GHz and CPIs of 2, 2 and 2. A program with an instruction count of  $1 \times 10^7$  can be divided into classes as follows: 20% class A, 50% class B, 30% class C.

1. What is the average CPI for each implementation? (10%)
2. What is the CPU execution time of this program for each implementation? (10%)

Answer:

1. • P1:

$$\sum_{i=1}^3 \text{CPI}_i \times \text{IC}_i = 1 \times 0.2 + 2 \times 0.5 + 3 \times 0.3 = 2.1$$

- P2:

$$\sum_{i=1}^3 \text{CPI}_i \times \text{IC}_i = 2 \times 0.2 + 2 \times 0.5 + 2 \times 0.3 = 2$$

2. • P1:

$$\text{CPU Time} = \frac{\text{IC} \times \text{CPI}}{\text{clock rate}} = \frac{1 \times 10^7 \times 2.1}{2.5\text{GHz}} = 8.4 \times 10^{-3}$$

- P2:

$$\text{CPU Time} = \frac{\text{IC} \times \text{CPI}}{\text{clock rate}} = \frac{1 \times 10^7 \times 2}{2\text{GHz}} = 0.01$$

### Question 2. (15%)

Consider the following sequence of instructions, and assume that it is executed on a five-stage pipelined datapath.

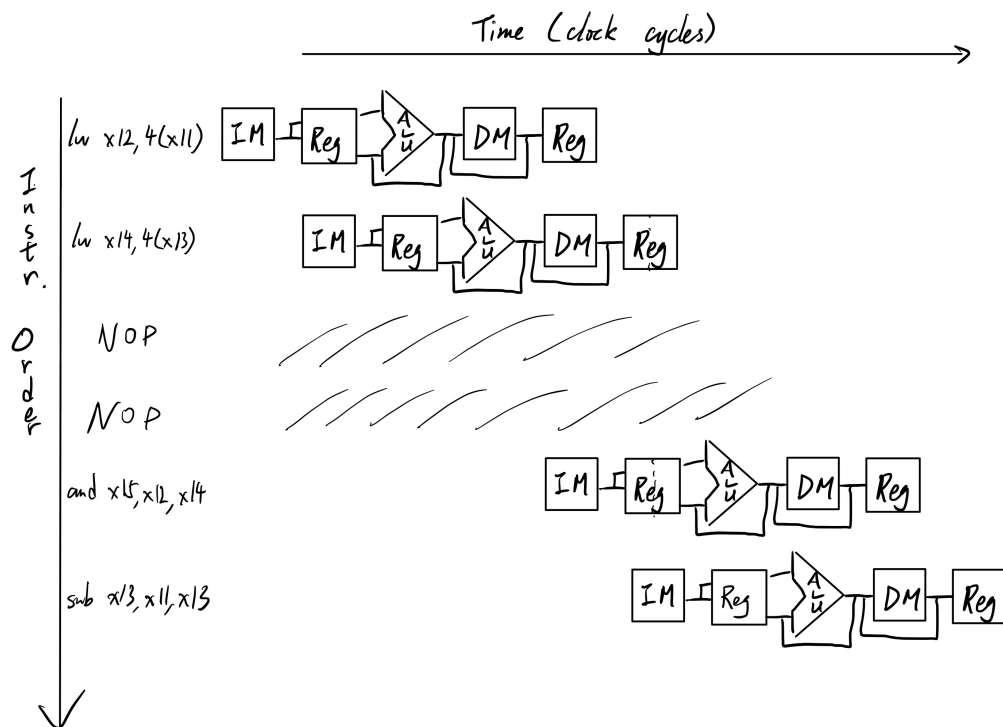
```

1    lw x12, 4(x11)
2    lw x14, 4(x13)
3    and x15, x12, x14
4    sub x13, x11, x13
  
```

1. If there is no forwarding or hazard detection, insert NOPs to ensure correct execution. You need to draw a pipeline diagram like we did in the lectures. (5%)
2. Does inserting NOPs change the clock cycle time? (5%)
3. Does inserting NOPs change the execute time of a program containing this block of code. (5%)

Answer:

1.



2. No, NOP will not affect clock cycle time
3. Yes, since the program containing this block of code will require more clock cycles to finish.

### Question 3. (25%)

Problems in this exercise refer to the following sequence of instructions, and suppose the instructions are executed on a five-stage pipelined datapath.

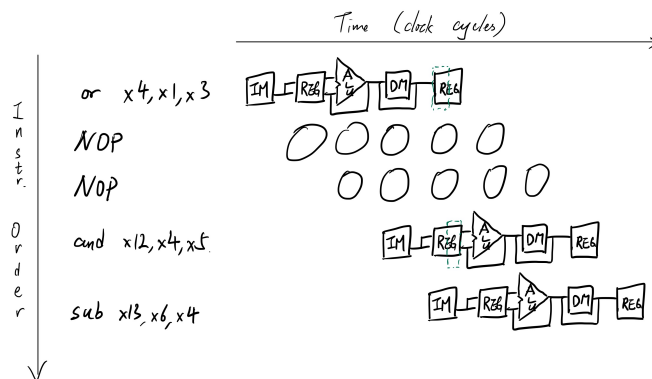
```

1    or x4, x1, x3
2    add x12, x4, x5
3    sub x13, x6, x4
  
```

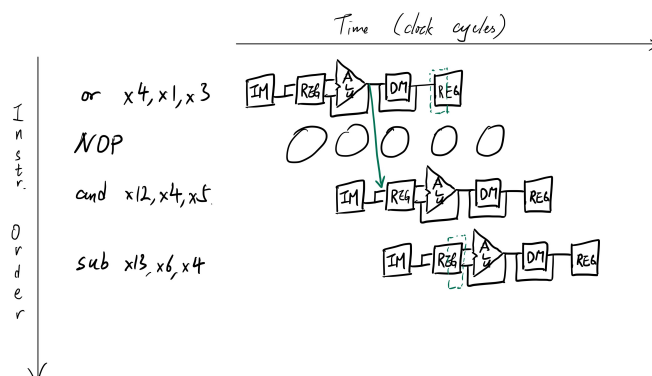
1. List the data dependencies of the three instructions. (5%)
2. If there is no forwarding or hazard detection, how many NOPs are needed to ensure correct execution. You need to draw a pipeline diagram as we did in the lectures. (10%)
3. If hazard detection and forwarding are allowed, draw a pipeline diagram **only with forwarding** to ensure correct execution. In the diagram, the forwarding need to be specified by an arrow. (10%)

Answer:

1. Write After Read(WAR)
2. 2 NOPs are required



3.



#### Question 4. (20%)

This exercise examines the accuracy of various branch predictors for the following repeating pattern (e.g., in a loop) of branch outcomes: T, NT, NT, T, T. (T means 'Taken' and NT means 'Not taken')

1. What is the accuracy of always-taken and always-not-taken predictors for this sequence of branch outcomes? (5%)
2. What is the accuracy of a 2-bit predictor if this pattern is repeated forever? You should give your explanations rather than just an answer. The table below is recommended. The following figure shows the finite-state machine for a 2-bit prediction scheme. Here we assume this predictor starts from "State 0". (15%)

Answer:

1.
  - always-taken: 60%
  - always-not-taken: 40%

	Iteration1	Iteration2	Iteration3	...
Actual	T NT NT T T	T NT NT T T	T NT NT T T	...
2. Predictor State	0,1,0,0,1	2,3,2,1,2	3,3,2,1,2	3,3,2,1,2
Prediction	N,N,N,N,N	T,T,T,N,T	T,T,T,N,T	T,T,T,N,T
True or False	F,T,T,F,F	T,F,F,F,T	T,F,F,F,T	T,F,F,F,T

$\therefore \text{Accuracy} = 2 \div 5 = 40\%$

### Question 5. (20%)

Assume a program requires the execution of  $50 \times 10^6$  FP instructions,  $110 \times 10^6$  INT instructions,  $80 \times 10^6$  L/S instructions, and  $16 \times 10^6$  branch instructions. The CPI for each type of instruction is 1, 1, 4, and 2, respectively. Assume that the processor has a 2 GHz clock rate.

1. By how much must we reduce the CPI of L/S instructions if we want the program to run two times faster? (10%)
2. By how much is the execution time of the program improved if the CPI of INT and FP instructions is reduced by 40% and the CPI of L/S and Branch is reduced by 30%? (10%)

Answer:

1. Let  $k$  be the number of CPI to be reduced,  $t$  be the execution time

$$\frac{1t}{3t} = \frac{\frac{25}{128} + \frac{55}{128} + (4-k)\frac{5}{16} + 2\frac{1}{16}}{\frac{25}{128} + \frac{55}{128} + 4\frac{5}{16} + 2\frac{1}{16}}$$

$$\frac{1t}{3t} = \frac{192 + (4-k)80}{512}$$
$$k = 2$$

- 2.

$$\frac{0.6 * 110 + 0.7 * 4 * 80 + 50 + 16 * 2}{110 + 4 * 80 + 50 + 16 * 2} = 72.6\%$$