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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 1×10^7 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.

```
lw x12, 4(x11)
lw x14, 4(x13)
and x15, x12, x14
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 excute time of a program containing this block of code. (5%)

Answer:

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.

```
    or x4, x1, x3
    add x12, x4, x5
    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:

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:

Question 5. (20%)

Assume a program requires the execution of 50 × 106 FP instructions, 110 × 106 INT instructions, 80 × 106 L/S instructions, and 16 × 106 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%)