HO CHI MINH UNIVERSITY OF TECHNOLOGY

Faculty of Computer Science and Engineering

COMPUTER ARCHITECTURE

Lab 1

Practical session - Week 1, Semester 1 2020

Lecturers: Assoc. Prof. Dr. Cuong Pham Quoc

Mr. Kieu Do Nguyen Binh

Class: CC04 Group:

Members: Nguyễn Minh Hùng - 1952737

Phạm Nhật Hoàng - 1952703

Nguyễn Bá Minh Hưng - 1952748

Question 1. Given three processors, P1, P2, and P3 executing the same instruction set with associated
parameters as shown in Table 1:

Processor	**Clock rate**	**Average CPI**
P1	3 GHz	1.5
P2	2.5 GHz	1.0
P3	4.0 GHz	2.2

Table 1: Information for Question 1

a. Which processor has the highest performance expressed in instruction per second?
b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of
instructions.
c. We are trying to reduce the time by 30% but this lead to an increase of 20% in the CPI. What clock rate
should we have to get this time reduction?

Answer

a. Performance $= \frac{1}{Excution\ time} = \frac{1}{CPU\ time} = \frac{1}{\frac{IC \times CPI}{Clock\ rate}} = \frac{Clock\ rate}{IC \times CPI}$

Because 3 processors execute the same instruction set, so they have the same IC.

Performance1 = $\frac{3 \times 10^9}{IC \times 1.5} = \frac{2 \times 10^9}{IC}$

Performance2 = $\frac{2.5 \times 10^9}{IC \times 1.0} = \frac{2.5 \times 10^9}{IC}$

Performance3 = $\frac{4 \times 10^9}{IC \times 2.2} = \frac{1.81 \times 10^9}{IC}$

- ⇨ P2 has the highest performance.

b. CPU time = $\frac{Cycles}{Clock\ rate} = \frac{IC \times CPI}{Clock\ rate}$

P1:

10 = $\frac{Cycles}{3 \times 10^9}$ => Cycles = 30 x 10^9 (cycles)

Instructions = IC = $\frac{Cycles}{CPI} = \frac{30 \times 10^9}{1.5}$ = 20 x 10^9 (instructions)

P2:

10 = $\frac{Cycles}{2.5 \times 10^9}$ => Cycles = 25 x 10^9 (cycles)

Instructions = IC = $\frac{Cycles}{CPI} = \frac{25 \times 10^9}{1.0}$ = 25 x 10^9 (instructions)

P3:

10 = $\frac{Cycles}{4 \times 10^9}$ => Cycles = 40 x 10^9 (cycles)

Instructions = IC = $\frac{Cycles}{CPI} = \frac{40 \times 10^9}{2.2}$ = 18.18 x 10^9 (instructions)

c. CPU time new = 70% CPU time => $\frac{IC \times CPInew}{Clock\ rate\ new} = 70\% \frac{IC \times CPI}{Clock\ rate}$

=> $\frac{IC \times 120\%\ CPI}{Clock\ rate\ new} = 70\% \frac{IC \times CPI}{Clock\ rate}$ => Clock rate new = $\frac{12}{7}$ Clock rate

P1 : Clock rate new = $\frac{12}{7}$ x 3 = 5.14 GHZ

P2: Clock rate new = $\frac{12}{7}$ x 2.5 = 4.29 GHZ

P3: Clock rate new = $\frac{12}{7}$ x 4.0 = 6.86 GHZ

Question 2. For problems below, use the information in the following table (Table 2):

Processor	Clock rate	No. Instruction	Time
P1	3 GHz	20 x 10^9	7 s
P2	2.5 GHz	30 x 10^9	10 s
P3	4.0 GHz	90 x 10^9	9 s

Table 2: Information for Question 2

a. Find the IPC (instructions per cycle) for each processor.
b. Find the clock rate for P2 that reduces its execution time to that of P1.
c. Find the number of instructions for P2 that reduces its execution time to that of P3

Answer

a. CPU time = $\frac{IC \times CPI}{Clock\ rate}$ => CPI = $\frac{CPU\ time \times Clock\ rate}{IC}$

IPC = $\frac{1}{Cycles\ per\ Instruction(CPI)} = \frac{IC}{CPU\ time \times Clock\ rate}$

P1: IPC = $\frac{20 \times 10^9}{7 \times 3 \times 10^9}$ = 0.95

P2: IPC = $\frac{30 \times 10^9}{10 \times 2.5 \times 10^9}$ = 1.2

P3: IPC = $\frac{90 \times 10^9}{9 \times 4 \times 10^9}$ = 2.5

b. Execution time = CPU time = $\frac{IC \times CPI}{Clock\ rate}$

For P2 : 7s = $\frac{IC \times CPI}{Clock\ rate\ new}$ => Clock rate new = $\frac{IC \times CPI}{7} = \frac{IC}{7 \times IPC} = \frac{30 \times 10^9}{7 \times 1.2}$ = 3.57 GHZ

c. Execution time = CPU time = $\frac{IC \times CPI}{Clock\ rate}$

For P2 : 9s = $\frac{IC\ new \times CPI}{Clock\ rate}$ => IC new = $\frac{9 \times Clock\ rate}{1/IPC}$ = 9 x 2.5 x 10^9 x 1.2 = 27 x 10^9 (instructions)

Question 3. Consider two different implementations of the same instruction set architecture. There are four classes of instructions, A, B, C, and D. The clock rate and CPI of each implementation are given in the following table (Table 3).

a. Given a program with 10^6 instructions divided into classes as follows: 10% class A, 20% class B, 50% class C, and 20% class D, which implementation is faster?

Processor	Clock rate	CPI A	CPI B	CPI C	CPI D
P1	2.5 GHz	1	2	3	3
P2	3 GHz	2	2	2	2

Table 3: Information for Question 3

b. What is the global CPI for each implementation?

c. Find the clock cycles required in both cases.

Answer

a. $\text{Performance} = \frac{1}{Excution\ time} = \frac{1}{CPU\ time} = \frac{Clock\ rate}{Clock\ cycles} = \frac{Clock\ rate}{\sum_{i=1}^{n}(CPIi \times ICi)}$

P1: Performance = $\frac{2.5 \times 10^9}{1 \times 10\% \times 10^6 + 2 \times 20\% \times 10^6 + 3 \times 50\% \times 10^6 + 3 \times 20\% \times 10^6}$

= 961.54

P2: Performance = $\frac{3 \times 10^9}{2 \times 10\% \times 10^6 + 2 \times 20\% \times 10^6 + 2 \times 50\% \times 10^6 + 2 \times 20\% \times 10^6}$

= 1500

⇨ P2 is faster than P1.

b. CPI average = $\frac{Clock\ cycles}{IC} = \frac{\sum_{i=1}^{n}(CPIi \times ICi)}{IC}$

P1: CPI global = $\frac{1 \times 10\% \times 10^6 + 2 \times 20\% \times 10^6 + 3 \times 50\% \times 10^6 + 3 \times 20\% \times 10^6}{10^6}$ = 2.6

P2: CPI global = $\frac{2 \times 10\% \times 10^6 + 2 \times 20\% \times 10^6 + 2 \times 50\% \times 10^6 + 2 \times 20\% \times 10^6}{10^6}$ = 2

c. Clock cycles = CPI global x IC

P1: Clock cycles = 2.6 x 10^6 (cycles)

P2: Clock cycles = 2 x 10^6 (cycles)

Question 4. A program consists of 1000 instructions in which 20% load store instructions, 10% jump instructions, 20% branch instructions, and arithmetic instructions. Assume that CPIs for those instructions are 2.5, 1, 1.5, and 2, respectively. The program is executed on a 2 GHz processor.

- What is the execution time of the above program?
- What is the average CPI of the above the program?
- Assume that we are trying to improve the load store instructions such that the execution time for this
instructions type is reduced by a factor of 2. What is the speed-up of the program?

Answer

- Execution time = CPU time = $\frac{Clock\ Cycles}{Clock\ rate} = \frac{\sum_{i=1}^{n}(CPIi \times ICi)}{Clock\ rate}$

$$= \frac{2.5 \times 20\% \times 1000 + 1 \times 10\% \times 1000 + 1.5 \times 20\% \times 1000 + 2 \times 50\% \times 1000}{2 \times 10^9}$$

= 950 ns

- CPI average = $\frac{\sum_{i=1}^{n}(CPIi \times ICi)}{IC} = \frac{2.5 \times 20\% \times 1000 + 1 \times 10\% \times 1000 + 1.5 \times 20\% \times 1000 + 2 \times 50\% \times 1000}{1000}$

= 1.9

- Speed-up = $\frac{new\ Performance}{old\ Performance} = \frac{\frac{Clock\ rate}{New\ Clock\ cycles}}{\frac{Clock\ rate}{Old\ Clock\ cycles}} = \frac{Old\ Clock\ cycles}{New\ Clock\ cycles}$

$$= \frac{2.5 \times 20\% \times 1000 + 1 \times 10\% \times 1000 + 1.5 \times 20\% \times 1000 + 2 \times 50\% \times 1000}{2.5 \times \frac{1}{2} \times 20\% \times 1000 + 1 \times 10\% \times 1000 + 1.5 \times 20\% \times 1000 + 2 \times 50\% \times 1000} = 1.15$$

(Execution time ~ CPI -> loadstore CPI new =2.5 x 1/2)

Question 5. Suppose we have made the following measurements:
- Frequency of FP operations = 25%
- Average CPI of FP operations = 4.0
- Average CPI of other instructions = 1.33
- Frequency of FPSQR= 2%
- CPI of FPSQR = 20

Assume that the two design alternatives are to decrease the CPI of FPSQR to 2 or to decrease the average
CPI of all FP operations to 2.5. Compare these two design alternatives using the processor performance
equation.

Answer

CPI original = FP freq × FP CPI + other freq × other CPI = 25% × 4.0 + 75% × 1.33 = 1.9975

Design 1: decrease the CPI of FPSQR to 2

In other instructions we have used above, that would include FPSQR instruction with 2% frequency. Therefore, the difference here is just the difference of FPSQR CPI.

CPI new – CPI original = FPSQR freq × (FPSQR CPI new – FPSQR CPI old)

CPI new = 2% × (2 – 20) + 1.9975 = 1.6375

⇨ Speed up $= \frac{New\ performance}{Old\ performance} = \frac{Old\ CPU\ time}{New\ CPU\ time} = \frac{CPI\ old}{CPI\ new} = \frac{1.9975}{1.6375} = 1.22$

Design 2: decrease the average CPI of all FP operations to 2.5

CPI new = FP freq × FP CPI new + other freq × other CPI = 25% × 2.5 + 75% × 1.33 = 1.6225

⇨ Speed up $= \frac{New\ performance}{Old\ performance} = \frac{Old\ CPU\ time}{New\ CPU\ time} = \frac{CPI\ old}{CPI\ new} = \frac{1.9975}{1.6225} = 1.23$

=>Therefore, the Design 2 would be better than Design 1.

Question 6. Assume a program requires the execution of:
- 50 x 10^6 FP instructions,
- 110 x 10^6 INT instructions,
- 80 x 10^6 L/S instructions,
- and 16 x 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.
a. By how much must we improve the CPI of FP instructions if we want the program to run two times faster?
b. By how much must we improve the CPI of L/S instructions if we want the program to run two times faster?
c. 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%?

Answer

a. CPU time new = $\frac{1}{2}$ CPU time old ⇔ $\frac{Clock\ Cycles\ new}{Clock\ rate} = \frac{1}{2}$ x $\frac{Clock\ Cycles\ old}{Clock\ rate}$

⇔ 10^6 x (50 x FP CPI new +110 x 1 +80 x 4 + 16 x 2) = $\frac{1}{2}$ x 10^6 x (50 x 1+110 x 1+80 x 4+16 x 2)

⇨ FP CPI new = - 4.12 (impossible, the CPI cannot be negative!)

Therefore, we couldn't have this reduction.

b. Same as question a) we would have:

10^6 x (50 x 1 +110 x 1 +80 x L/S CPI new + 16 x 2) = $\frac{1}{2}$ x 10^6 x (50 x 1+110 x 1+80 x 4+16 x 2)

⇨ LS CPI new = 0.8

$\frac{0.8}{4}$ = 0.2

⇨ Reduction of 80%.

c. Execution time = $\frac{\sum_{i=1}^{n}(CPIi \times ICi)}{Clock\ rate} = \frac{1\times50\times10^6+1\times110\times10^6+4\times80\times10^6+2\times16\times10^6}{2\times10^9}$

= 0.256 s

New Clock Cycles = $\sum_{i=1}^{n}(CPIi\ new\ \times\ ICi)$

$= 1 \times 60\% \times 50 \times 10^6 + 1 \times 60\% \times 110 \times 10^6 + 4 \times 70\% \times 80 \times 10^6 + 2 \times 70\% \times 16 \times 10^6$

= 342.4 x 10^6

⇨ Execution time new = $\frac{New\ Clock\ cycles}{Clock\ rate} = \frac{342.4 \times 10^6}{2 \times 10^9}$ = 0.1712 s

=>Improved time = Execution time old – Execution time new = 0.256 – 0.1712 = 0.0848 s