Tutorial 1 – Week of Sep 13, 2021

Questions: **(Page 60, Question 1.6)**

1) Q1.5

Consider three different processors P1, P2, and P3 executing the same instruction set. P1 has a 3 GHz clock rate and a CPI of 1.5. P2 has a 2.5 GHz clock rate and a CPI of 1.0. P3 has a 4.0 GHz clock rate and has a CPI of 2.2.

a. Which processor has the highest performance expressed in instructions 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 execution time by 30%, but this leads to an increase of 20% in the CPI. What clock rate should we have to get this time reduction?

Solution:

a. performance of P1 (instructions/sec) $= 3 \times 10^9/1.5 = 2 \times 10^9$

performance of P2 (instructions/sec) $= 2.5 \times 10^9/1.0 = 2.5 \times 10^9$

performance of P3 (instructions/sec) $= 4 \times 10^9/2.2 = 1.8 \times 10^9$

b. $\text{cycles}(P1) = 10 \times 3 \times 10^9 = 30 \times 10^9 \text{ s}$

$\text{cycles}(P2) = 10 \times 2.5 \times 10^9 = 25 \times 10^9 \text{ s}$

$\text{cycles}(P3) = 10 \times 4 \times 10^9 = 40 \times 10^9 \text{ s}$

c. $\text{No. instructions}(P1) = 30 \times 10^9/1.5 = 20 \times 10^9$

$\text{No. instructions}(P2) = 25 \times 10^9/1 = 25 \times 10^9$

$\text{No. instructions}(P3) = 40 \times 10^9/2.2 = 18.18 \times 10^9$

$\text{CPI}_{\text{new}} = \text{CPI}_{\text{old}} \times 1.2$, then $\text{CPI}(P1) = 1.8$, $\text{CPI}(P2) = 1.2$, $\text{CPI}(P3) = 2.6$

$f = \text{No. instr.} \times \text{CPI/time}$, then

$f(P1) = 20 \times 10^9 \times 1.8/7 = 5.14 \text{ GHz}$

$f(P2) = 25 \times 10^9 \times 1.2/7 = 4.28 \text{ GHz}$

$f(P3) = 18.18 \times 10^9 \times 2.6/7 = 6.75 \text{ GHz}$

2) Q1.8

Compilers can have a profound impact on the performance of an application. Assume that for a program, compiler A results in a dynamic instruction count of 1.0E9 and has an execution time of 1.1 s, while compiler B results in a dynamic instruction count of 1.2E9 and an execution time of 1.5 s.

a. Find the average CPI for each program given that the processor has a clock cycle time of 1 ns.

b. Assume the compiled programs run on two different processors. If the execution times on the two processors are the same, how much faster is the clock rate of the processor running compiler A's code versus the clock rate of the processor running compiler B's code?

c. A new compiler is developed that uses only 6.0E8 instructions and has an average CPI of 1.1. What is the speedup of using this new compiler versus using compiler A or B on the original processor?

Solution:

a. $CPI = T_{exec} \times f/\text{No. instr.}$

Compiler A $CPI = 1.1$

Compiler B $CPI = 1.25$

b. $f_B/f_A = (\text{No. instr.}(B) \times CPI(B))/(\text{No. instr.}(A) \times CPI(A)) = 1.37$

c. $T_A/T_{new} = 1.67$

$T_B/T_{new} = \cancel{2.27}$

2.73*

***Found by Qi Zhao**

3) Q 1.12

The results of the SPEC CPU2006 bzip2 benchmark running on an AMD Barcelona has an instruction count of 2.389E12, an execution time of 750 s, and a reference time of 9650 s.

1.12.1 Find the CPI if the clock cycle time is 0.333 ns.

1.12.2 Find the SPEC ratio.

1.12.3 Find the increase in CPU time if the number of instructions of the benchmark is increased by 10% without affecting the CPI.

1.12.4 Find the increase in CPU time if the number of instructions of the benchmark is increased by 10% and the CPI is increased by 5%.

1.12.5 Find the change in the SPEC ratio for this change.

1.12.6 Suppose that we are developing a new version of the AMD Barcelona processor with a 4 GHz clock rate. We have added some additional instructions to the instruction set in such a way that the number of instructions has been reduced by 15%. The execution time is reduced to 700 s and the new SPECratio is 13.7. Find the new CPI.

1.12.7 This CPI value is larger than obtained in 1.12.1 as the clock rate was increased from 3 GHz to 4 GHz. Determine whether the increase in the CPI is similar to that of the clock rate. If they are dissimilar, why?

1.12.8 By how much has the CPU time been reduced?

1.12.9 For a second benchmark, libquantum, assume an execution time of 960 s, CPI of 1.61, and clock rate of 3 GHz. If the execution time is reduced by an additional 10% without affecting the CPI and with a clock rate of 4 GHz, determine the number of instructions.

1.12.10 Determine the clock rate required to give a further 10% reduction in CPU time while maintaining the number of instructions and with the CPI unchanged.

Solution

1.12.1 CPI = clock rate × CPU time/instr. count

clock rate = 1/cycle time = 3 GHz

CPI(bzip2) = $3 \times 10^9 \times 750/(2389 \times 10^9) = 0.94$

1.12.2 SPEC ratio = reference time / execution time

SPEC ratio(bzip2) = 9650/750 = 12.86

1.12.3 CPU time = No. instr. × CPI/clock rate

If CPI and clock rate do not change, the CPU time increase is equal to the increase in the number of instructions, that is 10%.

1.12.4 CPU time(before) = No. instr. × CPI/clock rate

CPU time(after) = 1.1 × No. instr. × 1.05 × CPI/clock rate

CPU time(after)/CPU time(before) = 1.1 × 1.05 = 1.155. Thus, CPU time is increased by 15.5%.

1.12.5 SPECratio = reference time/CPU time

SPECratio(after)/SPECratio(before) = CPU time(before)/CPU time(after) = 1/1.1555 = 0.86. The SPECratio is decreased by 14%.

1.12.6 CPI = (CPU time × clock rate)/No. instr.

CPI = $700 \times 4 \times 10^9/(0.85 \times 2389 \times 10^9) = 1.37$

1.12.7 Clock rate ratio = 4 GHz/3 GHz = 1.33

CPI @ 4 GHz = 1.37, CPI @ 3 GHz = 0.94, ratio = 1.45

They are different because, although the number of instructions has been reduced by 15%, the CPU time has been reduced by a lower percentage.

1.12.8 700/750 = 0.933. CPU time reduction: 6.7%

1.12.9 No. instr. = CPU time × clock rate/CPI

No. instr. = $960 \times 0.9 \times 4 \times 10^9/1.61 = 2146 \times 10^9$

1.12.10 Clock rate = No. instr. × CPI/CPU time.

Clock rate_{new} = No. instr. × CPI/0.9 × CPU time = 1/0.9 clock rate_{old} = 3.33 GHz