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1. **(25 pts)** Consider three different processors P1, P2 and P3 executing the same instruction set. Clock rates and CPIs of the processors are given below.

Processor	Clock Rate	CPI
P1	2.0 GHz	1.0
P2	2.5 GHz	1.25
P3	3.0 GHz	2.5

a. (5 pts) Compute MIPS rates of the processors.

b. (5 pts) The programs C1, C2 and C3 are executed in P1, P2 and P3, respectively. All executions take 5 seconds. Find the number of instructions for each program.

c. (15 pts) The modification to reduce the execution time by 20%, leads to an increase of 20% in the CPI. What should be the new clock rates of the processors to achieve the targeted performance.

million (instruction per second)

P1 a-) $IPS = \frac{CR}{CPI}$ $MIPS = \frac{CR}{CPI} \cdot \frac{1}{10^6}$

$P1 \longrightarrow \frac{2 \cdot 10^9}{1 \cdot 10^6} = 2000$ MIPS

$P2 \longrightarrow \frac{2{,}5 \cdot 10^9}{1{,}25 \cdot 10^6} = 2000$ MIPS

$P3 \longrightarrow \frac{3 \cdot 10^9}{2{,}5 \cdot 10^6} = 1200$ MIPS

b-) instuctions = exectime . IPS, we already found MIPS; IPS is MIPS . 10^6

$C1 \longrightarrow \underbrace{2 \cdot 10^9}_{2 \cdot 10^3 \cdot 10^6} \cdot 5 = 10^{10}$ instructions

$C2 \longrightarrow \underbrace{2 \cdot 10^9}_{2 \cdot 10^3 \cdot 10^6} \cdot 5 = 10^{10}$ //

$C3 \longrightarrow \overbrace{1{,}2 \cdot 10^9}^{1{,}2 \cdot 10^3 \cdot 10^6} \cdot 5 = 6 \cdot 10^9$ //

C-) 20% less exec time $\Rightarrow$ $\frac{\text{instructions} \cdot \text{CPI}}{\text{clock rates}}$ is 80%

(*)

newCPI's:

$P1 \Rightarrow 1 \cdot \frac{120}{100} = 1{,}2 \ \frac{\text{cycle}}{\text{ins.}}$

$P2 \Rightarrow 1{,}25 \cdot \frac{120}{100} = 1{,}5 \ \frac{\text{cycle}}{\text{ins}}$

$P3 \rightarrow 2{,}5 \cdot \frac{120}{100} = 3 \ \frac{\text{cycle}}{\text{ins}}$

Same amount of instructions x, result should be 80% (exec time)

CRs: we will use (*):

P1 $\frac{\cancel{x} \cdot 1}{2 \cdot 10^9} \cdot \frac{80}{100} = \frac{\cancel{x} \cdot 1{,}2}{CR} \Rightarrow CR = 1{,}2 \cdot \frac{10}{8} \cdot 2 \cdot 10^9$

$= 3 \cdot 10^9 \Rightarrow 3 \text{ Ghz}$

these are clocks per second (pulses)

P2 $\frac{\cancel{x} \cdot 1{,}25}{2{,}5 \cdot 10^9} \cdot \frac{80}{100} = \frac{\cancel{x} \cdot 1{,}5}{CR} \Rightarrow CR = \frac{1{,}5}{1{,}25} \cdot \frac{10}{8} \cdot 2{,}5 \cdot 10^9$

$= 3{,}75 \cdot 10^9 \Rightarrow 3{,}75 \text{ Ghz}$

P3 $\frac{\cancel{x} \cdot 2{,}5}{3 \cdot 10^9} \cdot \frac{80}{100} = \frac{\cancel{x} \cdot 3}{CR} \Rightarrow CR = \frac{3}{2{,}5} \cdot \frac{10}{8} \cdot 3 \cdot 10^9$

$= 4{,}5 \cdot 10^9 \Rightarrow 4{,}5 \text{ Ghz}$

2. (**30 pts**) Consider two processors (P1 and P2) are the different implementations of the same ISA. The clock rates of the processors are 2.5 GHz and 3 GHz, respectively. The instructions are divided into three classes according to their CPIs, which are given below.

	P1	P2
Class A	1	2
Class B	1.5	2
Class C	3	2

Given a program with a dynamic instruction count of 10^6 instructions divided into classes as follows: 40% class A, 35% class B and 25% class D.

a. (**10 pts**) What is the global CPI for each implementation?

b. (**10 pts**) Find the clock cycles required in both cases.

c. (**10 pts**) Find the execution time in both cases.

P2.a

Global CPI = $CPI_1 \cdot usage_1 + \ldots + CPI_n \cdot usage_n$

P1 ⇒ $0{,}4 \cdot 1 + 1{,}5 \cdot 0{,}35 + 3 \cdot 0{,}25 = 1{,}675$ c/i (Global) CPI

P2 ⇒ $0{,}4 \cdot 2 + 0{,}35 \cdot 2 + 0{,}25 \cdot 2 = 2$ c/i (Global) CPI

b-) CC = CPI · instructions ; since we computed global CPI, we can use it to calculate clock cycles since it is a weighted average.

10^6

P1 → $1{,}675 \cdot 10^6$ cycles in total

P2 → $2 \cdot 10^6$ cycles in total

c-) exec_time = $\dfrac{\text{total clock cycles}}{\text{clock rate}}$ ⇒

P1 exec time

$$\frac{1{,}675 \cdot 10^6}{2{,}5 \cdot 10^9} = 6{,}7 \cdot 10^{-4}\,s$$

2,5 Ghz

P2 exectime

$$\frac{2 \cdot 10^6}{3 \cdot 10^9} = 6{,}66 \cdot 10^{-4}\,s$$

3 Ghz

3. **(30 pts)** Consider a given benchmark has an instruction count of 2.1 x 10^{12} and a reference time of 8000s. The execution of the benchmark takes 900 s on a processor with the cycle time of 0.25 ns.

a. **(10 pts)** Find the CPI of the processor.
b. **(5 pts)** Find the SPEC ratio of the processor.
c. **(15 pts)** Suppose that a new version of the processor with the clock rate of 4.5 GHz is developed. A couple of new instructions have been added to new design and the number of instructions has been reduced by 15%. The SPEC ratio for the new version is 12. Find the execution time and CPI of the new processor.

P3a) cycle time $= 0{,}25 \cdot 10^{-9} \Rightarrow CR = \frac{1}{\text{cycle time}} = 4 \cdot 10^{9}$ clock pulse per second ($= 4$ Ghz)

$\text{exec} = \frac{\text{total cycle}}{CR} = \frac{CPI \cdot \text{instructions}}{CR} \Rightarrow CPI = \frac{CR \cdot \text{exectime}}{\text{instructions}}$

$\Rightarrow CPI = \frac{4 \cdot 10^{9} \cdot 900}{2{,}1 \cdot 10^{12}} \approx 1{,}7142$ clock cycles per instruction

Bonus:
$\left(CPI = \frac{\text{cycles (total)}}{\text{instructions (total)}} \Rightarrow CC = ins \cdot CPI = 3{,}6 \cdot 10^{12} \text{ cycles in total} \right)$

b) $\text{SPECratio} = \frac{\text{Ref. time}}{\text{exec. time}} = \frac{8000}{900} \approx 8{,}8\overline{8}$

c) reduced instructions $\rightarrow 2{,}1 \cdot 10^{12} \cdot \frac{85}{100} = 1{,}785 \cdot 10^{12}$

$\text{Spec ratio} = \frac{8000}{\text{exectime}} = 12 \Rightarrow \text{exectime} = 666{,}67 \text{ sec}$

$4{,}5$ Ghz $\Rightarrow 4.5 \cdot 10^{9}$ cycles per second (CR)

$\left(\text{exec time} = \frac{\text{instructions} \cdot CPI}{CR} \right)$

$\text{exec} = \frac{\overbrace{1{,}785 \cdot 10^{12} \cdot CPI}^{\text{total cycles}}}{4{,}5 \cdot 10^{9}} = 666{,}67 \text{ sec}$

$\Rightarrow CPI = \frac{4{,}5 \cdot 10^{9} \cdot 666{,}67}{1{,}785 \cdot 10^{12}} = 1{,}6806 \frac{\text{clock cycles}}{\text{instruction}}$