CDA 4205 Computer Architecture

(1.5, 1.10, 1.13)

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Homework # 1
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$\boxed{1.5}$ Consider 3 different processors P_1, P_2 & P_3 executing the same instruction set. P_1 has a 3 GHz clock rate and a CPI of 1.5. P_2 has a 2.5 GHz clock rate and a CPI of 1.0. P_3 has a 4 GHz clock rate and a CPI of 2.2. < Section 1.6 >

A) Which processor has the highest performance expressed in instructions per second?

* Let I = instruction count

* $\text{CPU Time} = \dfrac{\text{Instruction Count} \times \text{CPI}}{\text{Clock rate}}$

$$P_1 \text{ CPU Time} = \frac{I \times 1.5}{3\,GHz} = \frac{I \times 1.5}{3 \times 10^9\,Hz} = I\left(\frac{1.5}{3 \times 10^9\,Hz}\right) = (5 \times 10^{-10}\,s)\,I$$

$$P_2 \text{ CPU Time} = \frac{I \times 1.0}{2.5\,GHz} = \frac{I \times 1.0}{2.5 \times 10^9\,Hz} = (4 \times 10^{-10}\,s)\,I$$

$$P_3 \text{ CPU Time} = \frac{I \times 2.2}{4\,GHz} = \frac{I \times 2.2}{4 \times 10^9\,Hz} = (5.5 \times 10^{-10}\,s)\,I$$

$\Rightarrow$ P_2 has the highest performance

B) If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions?

* CPU Time = 10 seconds
* Clock cycles = CPU Time x Clock rate
* Instruction count = clock cycles / CPI

$$\begin{cases} P_1 \text{ Clock cycles} = 10s\,(3GHz) = 10s\,(3\times10^9 Hz) = 3\times10^{10} \text{ cycles} \\ P_1 \text{ Instruction count} = \dfrac{(3\times10^{10}\text{ cycles})}{1.5} = 2\times10^{10} \text{ instructions} \end{cases}$$

$$\begin{cases} P_2 \text{ Clock cycles} = 10s\,(2.5GHz) = 10s\,(2.5\times10^9 Hz) = 2.5\times10^{10} \text{ cycles} \\ P_2 \text{ Instruction count} = \dfrac{(2.5\times10^{10}\text{ cycles})}{1.0} = 2.5\times10^{10} \text{ instructions} \end{cases}$$

$$\begin{cases} P_3 \text{ Clock cycles} = 10s\,(4\,GHz) = 10s\,(4\times10^9 Hz) = 4\times10^{10} \text{ cycles} \\ P_3 \text{ Instruction count} = \dfrac{(4\times10^{10}\text{ cycles})}{2.2} = 1.82\times10^{10} \text{ instructions} \end{cases}$$

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?

$$* \text{ CPU Time} = \frac{\text{Instr Count} \times CPI}{\text{Clock rate}}$$

$$* \text{ CPU Time}_x = (100-30\%)\text{ CPU Time}$$

$$* \text{ CPI}_x = CPI + CPI(20\%)$$

$$P_1 \text{ adjusted clock rate} = \frac{\text{Instr. Count} \times CPI_x}{\text{CPU Time}_x} = \frac{\text{Instr Count} \times [1.5 + 1.5(.20)]}{0.70\,(\text{CPU Time})}$$

$$= \frac{\cancel{\text{Instr. Count}} \times 1.8}{0.70\,(5\times10^{-10}s)(\cancel{\text{Instr. Count}})} = \frac{1.8}{0.70\,(5\times10^{-10}s)} = 5.14\times10^9\,Hz$$

$$P_2 \text{ adjusted clock rate} = \frac{\text{Instr Count} \times CPI_x}{\text{CPU Time}_x} = \frac{\cancel{\text{Instr Count}} \times [1.0 + 1.0(.20)]}{0.70\,(4\times10^{-10}s)(\cancel{\text{Instr Count}})}$$

$$= \frac{1.2}{0.70(4\times10^{-10}s)} = 4.28\times10^9\,Hz$$

$$P_3 \text{ adjusted clock rate} = \frac{\text{Instr. Count} \times CPI_x}{\text{CPU Time}_x} = \frac{2.64}{0.70\,(5.5\times10^{-10}s)} = 2.07\times10^9\,Hz$$

$\boxed{1.10}$ Assume a 15cm diameter wafer has a cost of 12, contains 84 dies, and has 0.020 defects / cm^2. Assume a 20 cm diameter wafer has a cost of 15, contains 100 dies, and has 0.031 defects / cm^2. < section 1.5 >

1.10.1) Find the yield for both wafers

* want the proportion of working dies per wafer
* $\text{Yield} = \dfrac{1}{(1 + (\text{defects per area} \times \text{die area}/2))^2}$
* die area ≈ wafer area / dies per wafer
* wafer area = πr^2

15cm wafer : wafer area = $\pi(7.5)^2 = 176.7\ cm^2$ die area ≈ $176.7\ cm^2 / 84 \approx 2.10\ cm^2$

$$\text{Yield} = \frac{1}{(1 + (0.02 \times 2.10/2))^2} = 0.96$$

20cm wafer: wafer area = $\pi(10)^2 = 314.16\ cm^2$ die area ≈ $314.16\ cm^2 / 100 \approx 3.14\ cm^2$

$$\text{Yield} = \frac{1}{(1 + (0.031 \times 3.14/2))^2} = 0.91$$

1.10.2) Find the cost per die for both wafers

* $\text{Cost per die} = \dfrac{\text{Cost per wafer}}{\text{Dies per wafer} \times \text{Yield}}$

15cm wafer : $\text{cost per die} = \dfrac{12}{84 \times 96\%} = 0.15$

20 cm wafer : $\text{cost per die} = \dfrac{15}{100 \times 91\%} = 0.16$

1.10.3) If the number of dies per wafer is increased by 10% and the defects per area unit increases by 15%, find the die area and yield.

15cm wafer : Die area ≈ wafer area /(Dies per wafer + Dies per wafer(.10))

$$\approx \pi(7.5)^2 / (84 + 84(.10))$$
$$\approx 176.7\ cm^2 / 92.4$$
$$\approx 1.91\ cm^2$$

$$\text{Yield} = \frac{1}{(1 + ([0.02 + 0.02(.15)] \times 1.91\,cm^2/2))^2} = \frac{1}{(1 + (.023 \times 1.91/2))^2} = 0.96$$

20 cm wafer : Die Area ≈ wafer area / (dies per wafer + dies per wafer (.10))

$$\approx 314.16\,cm^2 / (100 + 100(.10))$$

$$\approx 314.16\,cm^2 / 110$$

$$\approx 2.86\,cm^2$$

$$\text{Yield} = \frac{1}{(1 + ([0.031 + .031(.15)] \times 2.86\,cm^2/2))^2} = \frac{1}{(1 + (.036 \times 2.86/2))^2}$$

$$= 0.90$$

1.10.4) Assume a fabrication process improves the yield from 0.92 to 0.95. Find the defects per area unit for each version of the technology given a die area of 200 mm^2.

⇒ Did not understand the question's phrasing

1.13 Another pitfall cited in Section 1.10 is expecting to improve the overall performance of a computer by improving only one aspect of the computer. Consider a computer running a program that requires 250 s, with 70s spent executing FP instructions, 85s executed INT instruction, 55s execute L/S instructions, and 40s spent executing branch instructions. < 1.10 >

1.13.1) By how much is the total time reduced if the time for FP operations is reduced by 20%?

⇒ $FP_x = 70s\,(100 - 20\%) = 70s\,(.8) = 56s$

Total time = FP_x + INT + L/S + Branch = 236 s

⇒ 250s − 236s = 14s , where there is a (14/250 = 5.6) % reduction

1.13.2) By how much is the time for INT operations reduced if the total time is reduced by 20%?

⇒ Find total time after 20% reduction: $250s(100-20\%) = 200s$

⇒ Find percent time of INT instruction:

→ $\frac{85s \text{ for INT}}{250s \text{ Execution}} = 34\%$

→ $34\% \times 200s = 68s$ for reduced INT

→ $85s - 68s = 17s$ reduction

1.13.3) Can the total time be reduced by 20% by reducing only the time for branch instructions?

⇒ 40s for branch instructions = 16% ($^{40s}/_{250s}$) of execution time

No, the branch instructions only consume 16% of the total execution time thus the 20% reduction is not possible.

E.G. Assume the time for branch instructions are reduced by 99.9% ...

→ Branch = $40s(100-99.9) = 40s(.001) = 0.04s$

Total time = $FP + INT + L/S + 0.04 = 210.04s$

→ $250s - 210.04s = 39.96s$ giving a ($^{39.96}/_{250}$) 15.98% reduction, therefore reducing branch instructions will never yield a 20% reduction in total time.