Computer Architecture & Organization HW#1 21700034 곽영혜

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

a. which Processor has the highest performance expressed in instructions per second?

	P1	P2	P3
GHz	3	2.5	4.0
CPI	1.5	1.0	2.2

CPU Time = Instruction Count × CPI × Clock Cycle Time

$= \frac{\text{Instruction Count} \times \text{CPI}}{\text{Clock Rate}}$

CPU Time

$P1 = \frac{I.C \times 1.5}{3 \times 10^9} = \frac{I.C}{10^9} \times 0.5 = \frac{I.C}{10^9} \times \frac{1}{2}$

$P2 = \frac{I.C \times 1.0}{2.5 \times 10^9} = \frac{I.C}{10^9} \times \frac{1}{\frac{25}{10}} = \frac{I.C}{10^9} \times \frac{2}{5}$

$P3 = \frac{I.C \times 2.2}{4 \times 10^9} = \frac{I.C}{10^9} \times \frac{\frac{22}{10}}{4} = \frac{I.C}{10^9} \times \frac{11}{20}$

⇒ CPU Time Order

⇒ P3 > P1 > P2

Answer

: P2 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.

$\text{CPU Time} = \frac{\text{CPU Clock Cycles}}{\text{Clock Rate}}$ *each processors CPU Time is same (10 seconds)

CPU Clock Cycles = CPU Time × Clock Rate

$P1 = 10 \times 3 \times 10^9 = 30 \times 10^9$

$P2 = 10 \times 2.5 \times 10^9 = 25 \times 10^9$

$P3 = 10 \times 4 \times 10^9 = 40 \times 10^9$

Clock Cycles = Instruction Count × CPI

$\text{Instruction Count} = \frac{\text{Clock Cycles}}{\text{CPI}}$

$P1 = \frac{30 \times 10^9}{1.5} = \frac{30}{\frac{15}{10}} \times 10^9 = 20 \times 10^9$

$P2 = \frac{25 \times 10^9}{1.0} = 25 \times 10^9$

$P3 = \frac{40 \times 10^9}{2.2} = \frac{40}{\frac{22}{10}} \times 10^9 = \frac{200}{11} \times 10^9$

Answer

	Num of Cycles	Num of Instructions
P1	30×10^9	20×10^9
P2	25×10^9	25×10^9
P3	40×10^9	$\frac{200}{11} \times 10^9$

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?

$\text{CPU Time} = \frac{\text{Instruction Count} \times \text{CPI}}{\text{Clock Rate}}$

$\Rightarrow \text{Clock Rate} = \frac{I.C \times CPI}{\text{CPU Time}} \Rightarrow \frac{I.C \times CPI \times \overset{(+20\%)}{\frac{12}{10}}}{\text{CPU Time} \times \underset{(-30\%)}{\frac{7}{10}}} = \frac{12}{7} \times \frac{I.C \times CPI}{\text{CPU Time}}$

Answer : $\frac{12}{7}$ × Clock rate.

1.6 Consider two different implementations of the same instruction set architecture. The instructions can be divided into four classes according to their CPI (class A, B, C, and D). P1 with a clock rate of 2.5 GHz and CPIs of 1, 2, 3, and 3, and P2 with a clock rate of 3 GHz and CPIs of 2, 2, 2, and 2.

Given a program with a dynamic instruction count of 1.0E6 instructions divided into classes as follows: 10% class A, 20% class B, 50% class C, and 20% class D, which is faster: P1 or P2?

Instruction Class	A	B	C	D	Sum
P1	1	2	3	3	9
P2	2	2	2	2	8

Percentage of Class
A : 10%
B : 20%
C : 50%
D : 20%

Clock Rate
P1 : 2.5GHz
P2 : 3GHz

*Clock Cycles $= \sum_{i=1}^{n} (CPI_i \times \text{Instruction Count}_i)$

$$P1\ C.C = (1\times\tfrac{1}{10}\times 10^6) + (2\times\tfrac{2}{10}\times10^6) + (3\times\tfrac{5}{10}\times10^6) + (3\times\tfrac{2}{10}\times10^6)$$

10^6 → 1.0E6

$$= 10^5 + (4\times10^5) + (15\times10^5) + (6\times10^5) = (1+4+15+6)\times10^5$$
$$= 26\times10^5$$

$$P2\ C.C = (2\times\tfrac{1}{10}\times10^6) + (2\times\tfrac{2}{10}\times10^6) + (2\times\tfrac{5}{10}\times10^6) + (2\times\tfrac{2}{10}\times10^6)$$
$$= (2+4+10+4)\times10^5 = 20\times10^5$$

*CPU time $= \dfrac{\text{CPU Clock Cycles}}{\text{Clock Rate}}$

$$P1 = \frac{26\times10^5\ [\text{cycles}]}{2.5\times10^9\ [\text{cycles/sec}]} = \frac{26}{25\times10^3}\ \text{sec} = 0.001\ldots\ \text{sec}$$

$$P2 = \frac{20\times10^5\ [\text{cycles}]}{3\times10^9\ [\text{cycles/sec}]} = \frac{20}{3\times10^4}\ \text{sec} = 0.0006\ldots\ \text{sec}$$

Answer
: P2 is faster than P1.

a. What is the global CPI for each implementation?

*Global CPI = (CPU Time × Clock Rate) / Instruction Count

$$P1 = \left(\frac{26}{25\times10^3}\times 2.5\times10^9\right)/1.0\times10^6 = \frac{2.6}{1.0} = 2.6$$

$$P2 = \left(\frac{20}{3\times10^4}\times 3\times10^9\right)/1.0\times10^6 = \frac{20}{10} = 2$$

Answer
: P1's Global CPI = 2.6
P2's 〃 〃 = 2

b. Find the clock cycles required in both cases.

Answer
: P1's Clock Cycles : 2.6×10^6
P2's 〃 〃 : 2.0×10^6

1.7 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

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

Compiler	Instruction Count	Execution time
A	1×10^9	1.1S
B	1.2×10^9	1.5S

$$*CPI = \frac{\text{CPU Time}(=\text{execution time})}{\text{Instruction Count} \times \text{Clock Cycle Time}}$$

Answer

: A's Avg CPI $= \frac{1.1S}{1\times10^9 \times 1ns} = \frac{1.1S}{1\times10^9\times10^{-9}S} = 1.1$

B's .. .. $= \frac{1.5S}{1.2\times10^9\times1ns} = \frac{1.5S}{1.2\times10^9\times10^{-9}S} = \frac{\frac{15}{10}}{\frac{12}{10}} = \frac{5}{4} = 1.25$

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 of the processor running Compiler A's code versus the clock of the processor running Compiler B's code?

CPU Time (Execution times) = Instruction Count $\times$ CPI $\times$ $\underbrace{\text{Clock Cycle Time}}_{=C.C.T}$

$1\times10^9\times1.1\times$ A's C.C.T $= 1.2\times10^9\times1.25\times$ B's C.C.T

$1.1\times10^9\times$ A's C.C.T $= 1.5\times10^9\times$ B's C.C.T $\Rightarrow$ A's C.C.T > B's C.C.T

$1.5/1.1 \fallingdotseq 1.36..$

Answer

: The processor running Compiler B's Code is faster than the processor running Compiler A's code by 1.36.

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?

New Compiler CPI

$1.1 = \frac{\text{Clock Cycles}}{6\times10^8} \Rightarrow C.C = 6.6\times10^8$

A's CPI

$1.1 = \frac{C.C}{1\times10^9} \Rightarrow C.C = 1.1\times10^9 = 11\times10^8$

B's CPI

$1.25 = \frac{C.C}{1.2\times10^9} \Rightarrow C.C = 1.5\times10^9 = 15\times10^8$

Answer

: New Compiler is fastest among the three Compilers. It is faster than A by 1.6, B by 2.27

$\frac{A}{NC} = \frac{11\times10^8}{6.6\times10^8} = \frac{11}{\frac{66}{10}} = \frac{10}{6} = 1.6...$

$\frac{B}{NC} = \frac{15\times10^8}{6.6\times10^8} = \frac{15}{\frac{66}{10}} = \frac{50}{22} = 2.27..$

1.10 Assume a 15cm diameter Wafer has a cost of 12, Contains 84 dies, and has 0.020 defects/cm^2. Assume a 20cm diameter Wafer has a Cost of 15, Contains 100 dies, and has 0.031 defects/cm^2.

1.10.1 Find the yield for both wafers.

Diameter Wafer	Cost	Number of dies	Defects/cm^2
15cm	12	84	0.020
20cm	15	100	0.031

$$* \text{Yield} = \frac{1}{\{1 + (\text{Defects per area} \times \text{Die area}/2)\}^2}$$

$$\underbrace{\text{Dies per wafer}}_{=D.P.W} \approx \frac{\text{Wafer area}}{\text{Die area}}$$

$$\text{Die area} \approx \frac{\text{Wafer area}}{D.P.W}$$

Wafer	Die area
15cm	$\frac{(15/2)^2\pi\,[cm^2]}{84} = 2.1037\ldots cm^2$
20cm	$\frac{(10)^2\pi\,[cm^2]}{100} = \pi\, cm^2 = 3.14\ldots cm^2$

15cm Yield

$$= \frac{1}{\{1+(0.020\times 2.10/2)\}^2}$$

$$= \frac{1}{(1.021)^2} = 0.959\ldots = 0.95$$

20cm Yield

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

$$= \frac{1}{(1.04867)^2} = 0.909\ldots = 0.90$$

Answer

15cm Yield = 0.95
20cm Yield = 0.9

1.10.2 Find the cost per dies for both wafers.

$$* \underset{(=C.P.d)}{\text{Cost per die}} = \frac{\text{Cost per Wafer}}{\text{Dies per Wafer} \times \text{yield}}$$

$$15cm\ C.P.d = \frac{12}{84\times 0.95} = 0.1503\ldots$$

$$20cm\ '' = \frac{15}{100 \times 0.90} = 0.1666\ldots$$

Answer : 15cm Cost per die = 0.15
20cm " " " = $0.1\dot{6}$

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.

Diameter Wafer	Number of dies	Defects/cm^2
15cm	$84 \times \frac{110}{100} = 92.4$	$0.020 \times \frac{115}{100} = 0.023$
20cm	$100 \times \frac{110}{100} = 110$	$0.031 \times \frac{115}{100} = 0.3565$

$$* \text{Die area} \approx \frac{\text{Wafer area}}{\text{Dies per Wafer}}$$

$$15cm \text{ Die area} = \frac{(15/2)^2 \pi [cm^2]}{92.4} = 1.9154 cm^2$$

$$20cm \text{ 〃 〃} = \frac{(20/2)^2 \pi [cm^2]}{110} = 2.854 cm^2$$

15cm Yield

$$= \frac{1}{\{1 + (0.023 \times 1.91/2)\}^2}$$

$$= \frac{1}{(1.021965)^2} = 0.9615 \fallingdotseq 0.96$$

20cm Yield

$$= \frac{1}{\{1 + (0.031 \times 2.82/2)\}^2}$$

$$= \frac{1}{(1.04371)^2} = 0.9259 \ldots \fallingdotseq 0.92$$

Answer

Diameter Wafer	Die area	Yield
15cm	1.91	0.96
20cm	2.85	0.92

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 $200mm^2$.

$$* \text{Yield} = \frac{1}{\{1 + (\underbrace{\text{Defects per area}}_{(=DPA)} \times \underbrace{\text{Die area}}_{(=DA)}/2)\}^2}$$

$$= \left\{\frac{1}{1 + (DPA \times DA/2)}\right\}^2$$

$$\sqrt{\text{Yield}} = \sqrt{\left\{\frac{1}{1 + (DPA \times DA/2)}\right\}^{\cancel{2}}} = \frac{1}{1 + (DPA \times DA/2)}$$

$$1 + (DPA \times DA/2) = \frac{1}{\sqrt{\text{Yield}}} \Rightarrow DPA \times DA/2 = \frac{1}{\sqrt{\text{Yield}}} - 1$$

$$DPA = \left(\frac{1}{\sqrt{\text{Yield}}} - 1\right) \times \frac{2}{DA} \quad \left(\begin{array}{l}\text{Yield}: 0.92 \sim 0.95 \\ DA = 200mm^2 = 2cm^2\end{array}\right.$$

$$\begin{cases} = \left(\frac{1}{\sqrt{0.92}} - 1\right) \times \frac{\cancel{2}^1}{\cancel{2}_1} = 0.04257\ldots \\ = \left(\frac{1}{\sqrt{0.95}} - 1\right) \times \frac{\cancel{2}^1}{\cancel{2}_1} = 0.02597\ldots \end{cases}$$

Answer

yield	Defects per area
0.92	0.0425
0.95	0.0259

1.14 Assume a program requires the execution of 50×10^6 FP instructions, 110×10^6 INT instructions, 80×10^6 L/s instructions, and 16×10^6 branch instructions. The CPI for each type of instruction is 1, 1, 4, and 2, repectively. Assume that the processor has a 2 GHz clock rate.

1.14.1 By how much must we improve the CPI of FP instructions if we want the program to run two times faster?

* Clock Cycles $= \sum_{i=1}^{n} (CPI_i \times \text{Instruction Count}_i)$

$= (1 \times 50 \times 10^6) + (1 \times 110 \times 10^6) + (4 \times 80 \times 10^6) + (2 \times 16 \times 10^6)$

$= (50 + 110 + 320 + 32) \times 10^6 = 512 \times 10^6$

*According to the book page 34

CPU execution time $= \dfrac{\text{CPU Clock Cycles}}{\text{Clock Rate}} = \dfrac{512 \times 10^6}{2 \times 10^9} = 256 \times 10^{-3}/s$

$= 0.256$ sec

Improve the CPI of FP, run the program 2 times faster

$\Rightarrow \dfrac{\text{Clock Cycle}}{2} = (CPI.FP \times 50 \times 10^6) + (1 \times 110 \times 10^6) + (4 \times 80 \times 10^6) + (2 \times 16 \times 10^6)$

$256 \times 10^6 = (50\,CPI.FP + 462) \times 10^6$

$50\,CPI.FP = 256 - 462$ ($\Rightarrow \ominus$ value is not a improvement)

$= -206$

Answer: CPI of FP instructions could not improve becouse it has minus value.

1.14.2 By how much must we improve the CPI of L/s instructions if we want the program to run two times faster?

Improve the CPI of L/s, run the program 2 times faster

$\Rightarrow 256 \times 10^6 = (1 \times 50 \times 10^6) + (1 \times 110 \times 10^6) + (4 \times CPI.L/s \times 80 \times 10^6) + (2 \times 16 \times 10^6)$

$= (50 + 110 + 320 \cdot CPI.L/s + 32) \times 10^6$

$= (192 + 320 \cdot CPI.L/s) \times 10^6$

$320 \cdot CPI.L/s = 256 - 192 = 64 \quad CPI.L/s = \dfrac{64}{320} = \dfrac{8}{40} = \dfrac{1}{5} = 0.2$

Answer: We must improve the CPI of L/s instructions by 0.2 to run the program two times faster.

1.14.3 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%?

$$\text{Clock Cycle} = \left(\frac{6}{10} \times 50 \times 10^6\right) + \left(\frac{6}{10} \times 110 \times 10^6\right) + \left(4 \times \frac{7}{10} \times 80 \times 10^6\right) + \left(2 \times \frac{7}{10} \times 16 \times 10^6\right)$$

$$= (30 + 66 + 224 + 22.4) \times 10^6 = 342.4 \times 10^6$$

$$\text{CPU execution time} = \frac{342.4 \times 10^6}{2 \times 10^9} = 171.2 \times 10^{-3} = 0.1712 \text{ /sec}$$

$$\text{previous CPU execution time} = 0.256\text{/sec}$$

$$\frac{0.256}{0.1712} = 1.4953\ldots$$

Answer: Execution time improved 1.49 faster than before.