ZHEJIANG UNIVERSITY COLLEGE OF INFORMATION SCIENCE AND ELECTRONICS ENGINEERING

HOMEWORK #3

Computer Organization and Design

Name: Student ID:

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Problem 1.

There are 3 different processors P1, P2 and P3 with the same ISA, its clock frequencies and CPIs are as follow:

Processor	Clock Frequency	CPI
P1	2 GHz	1.5
P2	1.5 GHz	1.2
P3	3 GHz	2.0

1. Calculate the MIPS for each processor and find out which one has the best performance?
2. If we want to increase the MIPS by 30%, which will cause an increase of CPI by 15%, what's the clock frequency should be for each processor?

Answer: 1.According to the MIPS equation, the MIPS for each processor are as follows:

$$\text{MIPS} = \frac{\text{Instruction count}}{\frac{\text{Instruction count} \times \text{CPI}}{\text{Clock rate}} \times 10^6} = \frac{\text{Clock rate}}{\text{CPI} \times 10^6}$$

$$\text{MIPS}_{P1} = \frac{2 * 10^9}{1.5 * 10^6} = \frac{4}{3} \times 10^3 \tag{1}$$

$$\text{MIPS}_{P2} = \frac{1.5 * 10^9}{1.2 * 10^6} = 1.25 \times 10^3 \tag{2}$$

$$\text{MIPS}_{P3} = \frac{3 * 10^9}{2.0 * 10^6} = 1.5 \times 10^3 \tag{3}$$

Therefore, the P3 processor has the best performance.

2.

$$Clockrate = MIPS \times CPI \times 10^6 \tag{4}$$

$$\text{Clock rate}_{P1} = 130\% \times \frac{4}{3} \times 10^3 \times 115\% \times 1.5 \times 10^6 = 2.99GHz \tag{5}$$

$$\text{Clock rate}_{P2} = 130\% \times 1.25 \times 10^3 \times 115\% \times 1.2 \times 10^6 = 2.2425GHz \tag{6}$$

$$\text{Clock rate}_{P3} = 130\% \times 1.5 \times 10^3 \times 115\% \times 2.0 \times 10^6 = 4.485GHz \tag{7}$$

Problem 2.

The table below shows the instruction type breakdown of a given application executed on 1, 2, 4, or 8 processors. Using this data, you will be exploring the speedup of applications on parallel processors.

Processors	No. Instructions per processor			CPI		
	Arithmetic	Load/Store	Branch	Arithmetic	Load/Store	Branch
1	2560	1280	256	1	4	2
2	1280	640	128	1	5	2
4	640	320	64	1	7	2
8	320	160	32	1	12	2

1.1 The table above shows the number of instructions required per processor to complete a program on a multiprocessor with 1, 2, 4, or 8 processors. What is the total number of instructions executed per processor? What is the aggregate number of instructions executed across all processors?

1.2 Given the CPI values on the right of the table above, find the total execution time for this program on 1, 2, 4, and 8 processors. Assume that each processor has a 2 GHz clock frequency.

1.3 If the CPI of the arithmetic instructions was doubled, what would the impact be on the execution time of the program on 1, 2, 4, or 8 processors? Assume that each processor has a 2 GHz clock frequency.

The table below shows the number of instructions per processor core on a multicore processor as well as the average CPI for executing the program on 1, 2, 4, or 8 cores. Using this data, you will be exploring the speedup of applications on multicore processors.

Cores per Processor	Instructions per Core	Average CPI
1	1.00E+**10**	1.2
2	5.00E+**9**	1.4
4	2.50E+**9**	1.8
8	1.25E+**9**	2.6

1.4 Assuming a 3 GHz clock frequency, what is the execution time of the program using 1, 2, 4, or 8 cores?

1.5 If using a single core, find the required CPI for this core to get an execution time equal to the time obtained by using the number of cores in the table above (execution times in problem 1.4). Note that the number of instructions should be the aggregate number of instructions executed across all the cores.

Answer :

1.1

- For 1 Processor:

$$\text{Total Instructions per Processor} = 2560 + 1280 + 256 = 4096$$

$$\text{Aggregate Instructions} = 4096 \times 1 = 4096$$

- For 2 Processors:

$$\text{Total Instructions per Processor} = 1280 + 640 + 128 = 2048$$

$$\text{Aggregate Instructions} = 2048 \times 2 = 4096$$

- For 4 Processors:

$$\text{Total Instructions per Processor} = 640 + 320 + 64 = 1024$$

$$\text{Aggregate Instructions} = 1024 \times 4 = 4096$$

- For 8 Processors:

$$\text{Total Instructions per Processor} = 320 + 160 + 32 = 512$$

$$\text{Aggregate Instructions} = 512 \times 8 = 4096$$

1.2

$$\text{Execution Time (per processor)} = \left(\frac{\text{Instructions of Type}}{\text{Clock Frequency}} \times \text{CPI of Type} \right)$$

Assume clock frequency $f = 2\,\text{GHz}$:

$$\text{Execution Time} = \frac{\text{Instructions (Arithmetic)} \times \text{CPI (Arithmetic)}}{f} + \frac{\text{Instructions (Load/Store)} \times \text{CPI}}{f}$$

- For 1 Processor:
$$\text{Execution Time} = \frac{2560 \times 1}{2} + \frac{1280 \times 4}{2} + \frac{256 \times 2}{2} = 1280 + 2560 + 256 = 4096\,\text{ns}$$
- For 2 Processors:
$$\text{Execution Time} = \frac{1280 \times 1}{2} + \frac{640 \times 5}{2} + \frac{128 \times 2}{2} = 640 + 1600 + 128 = 2368\,\text{ns}$$
- For 4 Processors:
$$\text{Execution Time} = \frac{640 \times 1}{2} + \frac{320 \times 7}{2} + \frac{64 \times 2}{2} = 320 + 1120 + 64 = 1504\,\text{ns}$$
- For 8 Processors:
$$\text{Execution Time} = \frac{320 \times 1}{2} + \frac{160 \times 12}{2} + \frac{32 \times 2}{2} = 160 + 960 + 32 = 1152\,\text{ns}$$

1.3

- For 1 Processor:
$$\text{Execution Time} = \frac{2560 \times 2}{2} + \frac{1280 \times 4}{2} + \frac{256 \times 2}{2} = 2560 + 2560 + 256 = 5376\,\text{ns}$$
- For 2 Processors:
$$\text{Execution Time} = \frac{1280 \times 2}{2} + \frac{640 \times 5}{2} + \frac{128 \times 2}{2} = 1280 + 1600 + 128 = 3008\,\text{ns}$$
- For 4 Processors:
$$\text{Execution Time} = \frac{640 \times 2}{2} + \frac{320 \times 7}{2} + \frac{64 \times 2}{2} = 640 + 1120 + 64 = 1824\,\text{ns}$$
- For 8 Processors:
$$\text{Execution Time} = \frac{320 \times 2}{2} + \frac{160 \times 12}{2} + \frac{32 \times 2}{2} = 320 + 960 + 32 = 1312\,\text{ns}$$

1.4

- For 1 Core:
$$\text{Execution Time} = \frac{1.00 \times 10^{10} \times 1.2}{3 \times 10^9} = \frac{1.2 \times 10^{10}}{3 \times 10^9} = 4\,\text{seconds}$$
- For 2 Cores:
$$\text{Execution Time} = \frac{5.00 \times 10^9 \times 1.4}{3 \times 10^9} = \frac{7.00 \times 10^9}{3 \times 10^9} = \frac{7}{3}\,\text{seconds}$$
- For 4 Cores:
$$\text{Execution Time} = \frac{2.50 \times 10^9 \times 1.8}{3 \times 10^9} = \frac{4.50 \times 10^9}{3 \times 10^9} = 1.5\,\text{seconds}$$
- For 8 Cores:
$$\text{Execution Time} = \frac{1.25 \times 10^9 \times 2.6}{3 \times 10^9} = \frac{3.25 \times 10^9}{3 \times 10^9} = \frac{13}{12}\,\text{seconds}$$

1.5

- For 2 Cores:

$$\text{Aggregate Instructions} = 5.00 \times 10^9 \times 2 = 1.00 \times 10^{10}$$

$$\text{CPI}_{\text{required}} = \frac{\frac{7}{3}\text{seconds} \times 3 \times 10^9}{1.00 \times 10^{10}} = \frac{7 \times 10^9}{1.00 \times 10^{10}} = 0.7$$

- For 4 Cores:

$$\text{Aggregate Instructions} = 2.50 \times 10^9 \times 4 = 1.00 \times 10^{10}$$

$$\text{CPI}_{\text{required}} = \frac{1.5\text{seconds} \times 3 \times 10^9}{1.00 \times 10^{10}} = \frac{4.5 \times 10^9}{1.00 \times 10^{10}} = 0.45$$

- For 8 Cores:

$$\text{Aggregate Instructions} = 1.25 \times 10^9 \times 8 = 1.00 \times 10^{10}$$

$$\text{CPI}_{\text{required}} = \frac{\frac{13}{12}\text{seconds} \times 3 \times 10^9}{1.00 \times 10^{10}} = \frac{3.25 \times 10^9}{1.00 \times 10^{10}} = 0.325$$