Lab 7

Processor Performance

$$MIPS = \frac{IC}{CPU_{time} \times 10^6} = \frac{CR}{CPI \times 10^6}$$

$$CPU_{time} = \frac{IC \times CPI}{CR}$$

$$MFLOPS = \frac{FLOPS}{CPU_{time} \times 10^6}$$

$$speedup = \frac{CPU_{time\ old}}{CPU_{time\ new}} = \frac{1}{1 - f + \frac{f}{s}}$$

$$CPU_{time}\ enhanced = \frac{\text{Portion optimized}}{\text{Speedup optimize}} + CPU_{time}\ \text{enhanced}$$

$CPU_{time} = 100\,s$

multiplay operations - 80% of all instr.

improve multiply perf. to exec. the program 5 times faster

$CPU_{time\ new} = 20\,s$

$$20\,s = \frac{80\,s}{x} + (100 - 80)\,s$$

$$20\,s = \frac{80\,s}{x} + 20\,s$$ Nope

CPU ->

	IC	CPI
ALU	2.56 E9	1
L/S	1.28 E9	12
Branch	256 mill	5

As we parallelize to run multicore, number of ALU and L/S instr. are divided by 0.7 for each core, Branch instr. remain the same

Branch | 256 million | 5

As we parallelize to run multicore, number of ALU and L/S instr are divided by 0,7 for each core; Branch instr remain the same.

a) Total execution time for 1, 2, 4 cores

b) Relative speedups of the 2, 4 relative to single core

c) if the CPI of ALU instr was doubled, what is the impact on the CPU_{time} for 1, 2, cores?

d) To what the L/S CPi be reduced to match 1, 2 core performance to 4 core unhanced?

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a) $$CPU_{time\,1} = \frac{IC \times CPI}{CR} = \frac{CC}{CR}$$

$$\frac{CC}{CR} = \frac{2{,}56 \cdot 10^9 + 1{,}28 \cdot 10^9 \cdot 12 + 0{,}256 \cdot 10^9 \cdot 5}{2 \cdot 10^9}$$

$$\underline{CPU_{time\,1} = 9.61\ s}$$

$$CPU_{time\,2} = \frac{\left(\frac{2.56 \cdot 1}{2 \cdot 0{,}7} + \frac{1.28 \cdot 12}{2 \cdot 0{,}7} + 0{,}256 \cdot 5\right) \cdot 10^9}{2 \cdot 10^9}$$

$$\underline{CPU_{time\,2} = 7{,}04\ s}$$

$$\text{CPU time } 4 = \frac{CC}{CR} = 3 \cdot 1,28 = 3,84 \quad 1$$

$$CC_4 = 10^9 \left(\frac{14 \cdot 1,28}{2,8} + 1,28 \right) = 10^9 \cdot 6 \cdot 1,28$$

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b) $$speedup_2 = \frac{\text{CPU time } 1}{\text{CPU time } 2} = 1,36$$

$$speedup_4 = \frac{\text{CPU time } 1}{\text{CPU time } 4} = 2,5$$

c) $$\text{CPU}_{\text{time } 1 \text{ new}} = \frac{\text{Portion enhanced}}{\text{speedup}} + \text{Portion unenhanced}$$

1 1 1

anfism.

$$= \frac{\frac{2,56 \cdot 10^9}{2 \cdot 10^9}}{\frac{1}{2}} + \frac{1,28 \cdot 10^9 \cdot 12 + 0,256 \cdot 10^9 \cdot 5}{2 \cdot 10^9}$$

$$= \frac{2 \cdot 2,56 + 1,28 + 0,256}{2,56 + 1,28 + 0,256} = \frac{20+5+1}{10+5+1} = \frac{26}{16} = 1,625$$

1.14, 1.15 + 1.9

1.14 Assume a program requires the execution of 50 × 106 FP instructions, 110 × 106 INT instructions, 80 × 106 L/S instructions, and 16 × 106 branch instructions. The CPI for each type of instruction is 1, 1, 4, and 2, respectively. Assume that the processor has a 2 GHz clock rate.

1.14.1 [10] <§1.10> By how much must we improve the CPI of FP instructions if we want the program to run two times faster?

1.14.2 [10] <§1.10> By how much must we improve the CPI of L/S instructions if we want the program to run two times faster?

1.14.3 [5] <§1.10> 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%?

CR = 2 GHz

OP	CPI	IC
FP	1	50 × 106
INT	1	110 × 106
L/S	4	80 × 106
Br	2	16 × 106

CPI for FP improve for 2x speedup

$$CPU_{time}\ old = \frac{IC \times CPI\ (=CC)}{CR} = \frac{54272}{2 \cdot 10^9} = 27 \cdot 10^{-6}$$

$\underline{27\ \mu s}$

$$CC = 1 \times 50 \times 106 + 1 \times 110 \times 106 + 4 \times 80 \times 106 + 2 \times 16 \times 106 = 106(50 + 110 + 320 + 32)$$
$$= 54272$$

$$\text{CPU time}_{new} = \frac{\text{CPU time}_{old}}{2} = 13{,}5\ \mu s$$

$$\text{CPU time}_{new} = \frac{CC_{new}}{CR}$$

$$CC_{new} = IC_1 \times CPI_1 + \ldots$$

$$= IC_{FP} \times CPI_{FP} + IC_{INT} * CPI_{INT} \ldots$$

$$= 50 \times 10^6 * CPI_{FP} + 110 \times 10^6 +$$

$$+ 4 \times 80 \times 10^6 + 2 \times 16 \times 10^6 =$$

$$= (50 \times \underline{CPI_{FP}} + 110 + 320 + 32) \times 10^6$$

$$CC_{new} = CR \times \text{CPU time}_{new} = 2 \cdot 10^9 \cdot 13{,}5 \cdot 10^{-6}$$
$$= 27000$$

$$50 \cdot x + \overbrace{110 + 320 + 32}^{>254} = 254$$

$$\rightarrow x < 0 \rightarrow$$ Impossible for CPI to be negative ✓

CPI for L/S for 2x speedup

$$speedup = \frac{CPU_{time\ old}}{new} \Rightarrow$$

$$CPU\ time\ new = 13{,}5\ \mu s$$

$$CC_{new} = 1 \times 50 \times 10^6 + 110 \times 10^6 +$$

$$+ CPI_{L/S\ new} \times 80 \times 10^6 + 2 \times 16 \times 10^6$$

$$= 10^6 \left(50 + 110 + CPI_{L/S\ new} \times 80 + 32 \right)$$

$$13{,}5 \cdot 10^{-6} = \frac{CC_{new}}{2 \cdot 10^9} \Rightarrow 27\,000 = 10^6 \left(192 + 80 \times CPI \right)$$

$$192 + 80 \times CPI_{L/S_{new}} = 254{,}7$$

$$80 \times CPI_{L/S\ new} = 62$$

$$CPI_{L/S\ new} \sim 0{,}78$$

$$CPI\ improvement = \frac{4}{0{,}78} \sim 5{,}12\ times$$

CPI int and FP ↘ 40%

CPI L/S and Br ↘ 30%

Speedup = ?

$$CPU_{time\ new} = \frac{CC_{new}}{CR} \checkmark$$

$$CC_{new} = 1 \times 50 \times 10^6 \times \frac{60}{100} + 1 \times 110 \times 10^6 \times \frac{60}{100}$$
$$+ 4 \times 80 \times 10^6 \times \frac{70}{100} + 2 \times 16 \times 10^6 \times \frac{70}{100}$$

$$CC_{new} = \frac{10^6}{100}\left(50 \times 60 + 110 \times 60 + 320 \times 70 + 32 \times 70\right)$$

$$CC_{new} = \frac{10^6}{100} \cdot 34240 = 36.294,4$$

$$CPU_{time\ new} = 18,152 \mu s$$

$$speedup = \frac{27}{16} \sim \underline{\underline{1,5}}.$$

1.15 [5] <§1.8> When a program is adapted to run on multiple processors in a multiprocessor system, the execution time on each processor is comprised of computing time and the overhead time required for locked critical sections and/or to send data from one processor to another.

Assume a program requires t = 100 s of execution time on one processor. When run *p* processors, each processor requires t/p s, as well as an additional 4 s of overhead, irrespective of the number of processors. Compute the per-processor execution time for 2, 4, 8, 16, 32, 64, and 128 processors. For each case, list the corresponding speedup relative to a single processor and the ratio between actual speedup versus ideal speedup (speedup if there was no overhead).

CPU_{time} = Computing + Overhead

t = 100 s $\quad$ CPU_{time} 1 Core

t = 100 s $\quad$ p = 1

$\rightsquigarrow$ t/p + 4 s (overhead)

p	ideal time	real time	real speedup	relative speedup
1	100	100	1	1
2	50	54	1,85	1,08
4	25	29	3,45	1,16
8	12,5	16,5	6,06	1,32
16	6,25	10,25	9,756	1,64
32	3,125	7,125	14	2,28
64	1,5625	5,5625	18	3,56
128	0,78125	4,78125	20,9	6,12

1.9 Assume for arithmetic, load/store, and branch instructions, a processor has CPIs of 1, 12, and 5, respectively. Also assume that on a single processor a program requires the execution of 2.56E9 arithmetic instructions, 1.28E9 load/store instructions, and 256 million branch instructions. Assume that each processor has a 2 GHz clock frequency.

Assume that, as the program is parallelized to run over multiple cores, the number of arithmetic and load/store instructions per processor is divided by 0.7 x *p* (where *p* is the number of processors) but the number of branch instructions per processor remains the same.

1.9.1 [5] <§1.7> Find the total execution time for this program on 1, 2, 4, and 8 processors, and show the relative speedup of the 2, 4, and 8 processor result relative to the single processor result.

INSTR	CPI	IC
ALU	1	$2.56 \cdot 10^9$
L/S	12	$1,28 \cdot 10^9$
Br	5	$256 \cdot 10^6$

$CR = 2GHz$

p processors $\rightarrow \dfrac{IC_{ALU} + IC_{L/S}}{0,7 \times p}$

$$CPU_{time\ 1} = \frac{CC_1}{CR} = \frac{19,2 \cdot \cancel{10^9}}{2 \cdot \cancel{10^9}} = \boxed{9,6\ s}$$

$$CC_1 = 2.56 \cdot 10^9 + 12 \cdot 1,28 \cdot 10^9 + \underbrace{5 \cdot 256 \cdot 10^6}_{1,28 \cdot 10^9}$$

$$= (2,56 + 15,36 + 1,28) \cdot 10^9$$

$$= 19,2 \cdot 10^9$$

$$CPU_{time\,2} = \frac{CC_2}{CR} = \frac{14{,}08 \cdot \cancel{10^9}}{2 \cdot \cancel{10^9}} = \boxed{7{,}04\ s}$$

$$CC_2 = \frac{1 \cdot 2{,}56 \cdot 10^9}{0{,}7 \cdot 2} + \frac{12 \cdot 1{,}28 \cdot 10^9}{0{,}7 \cdot 2} + 1{,}28 \cdot 10^9$$

$$= 10^9 (1{,}83 + 10{,}97 + 1{,}28) = 14{,}08 \cdot 10^9$$

$$CPU_{time\,4} = \frac{CC_4}{CR} = \frac{7{,}68 \cdot 10^9}{2 \cdot 10^9} = \boxed{3{,}84\ s}$$

$$CC_4 = \frac{1 \cdot 2{,}56 \cdot 10^9}{0{,}7 \cdot 4} + \frac{12 \cdot 1{,}28 \cdot 10^9}{0{,}7 \cdot 4} + 1{,}28 \cdot 10^9$$

$$= 10^9 (0{,}914 + 5{,}4857 + 1{,}28) = 7{,}68 \cdot 10^9$$

$$CPU_{time\,8} = \frac{CC_8}{CR} = \frac{4{,}48 \cdot 10^9}{2 \cdot 10^9} = \boxed{2{,}24\ s}$$

$$CC_8 = \frac{1 \cdot 2{,}56 \cdot 10^9}{0{,}7 \cdot 8} + \frac{12 \cdot 1{,}28 \cdot 10^9}{0{,}7 \cdot 8} + 1{,}28 \cdot 10^9$$

$$= 10^9 (0{,}457 + 2{,}743 + 1{,}28) = 4{,}48 \cdot 10^9$$

CPU P	CPU time	Relative Speedup
1	9,6 s	1
2	7,04 s	1,36
4	3,84 s	2,5
8	2,24 s	4,28

1.9.2 [10] <§§1.6, 1.8> 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?

1.9.3 [10] <§§1.6, 1.8> To what should the CPI of load/store instructions be reduced in order for a single processor to match the performance of four processors using the original CPI values?

$$CPU_{time\ 1\ new} = \frac{CC_{1\ new}}{CR}$$

$$CC1\ new = 2 \cdot 2{,}56 \cdot 10^9 + 12 \cdot 1{,}28 \cdot 10^9 + 1{,}28 \cdot 10^9$$

$$Speedup = \frac{CPU_{time\ old}}{CPU_{time\ new}} = \frac{CC_{1\ old}}{CC_{1\ new}}$$

$$CPU_{time\ 1\ new} = CPU_{time\ 4\ old}$$

$$CC_{1\ new} = CC_{4\ old}$$

$$CC_{1\ new} = 2{,}56 \cdot 10^9 + CPI_{LS\ new} \cdot 1{,}28 \cdot 10^9 + 1{,}28 \cdot 10^9$$
