

# Lab 7

## Processor Performance

$$\text{MIPS} = \frac{\text{IC}}{\text{CPU}_{\text{time}} \times 10^6} = \frac{\text{CR}}{\text{CPi} \times 10^6}$$

$$\text{CPU}_{\text{time}} = \frac{\text{IC} \times \text{CPI}}{\text{CR}}$$

$$\text{MFLOPS} = \frac{\text{FLOPS}}{\text{CPU}_{\text{time}} \times 10^6}$$

$$\text{speedup} = \frac{\text{CPU}_{\text{time old}}}{\text{CPU}_{\text{time new}}} = \frac{1}{1 - f + \frac{f}{b}}$$

$$\text{CPU}_{\text{time enhanced}} = \frac{\text{Portion optimized}}{\text{Speedup optimized}} + \text{CPU}_{\text{time enhanced}}$$

CPU time = 100 s

multiply operations - 80% of all instr.

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

CPU time <sub>new</sub> = 20 s

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

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

CPU	FC	CPI
ALU	2.56 E9	1
L/S	1.28 E9	12
Branch	2.56 mill	5

As we parallelize to run multicore, number of ALU and L/S inst. are divided by 9.7 for each core, Branch instr. remain the same

Branch 256 million 5

As we parallelize to run multicores,  
number of ALU and L1s 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 speedup 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 L1s CPI be reduced to match 1, 2 core performance to 4 core unshared?

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$$a) \text{CPU}_{\text{time}1} = \frac{IC \times CPI}{CR} = \frac{CC}{CR}$$

$$\frac{CC}{CR} = \frac{2,56 \cdot 10^8 + 1,28 \cdot 10^9 \cdot 12 + 0,256 \cdot 10^8 \cdot 5}{2 \cdot 10^8}$$

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$$\text{CPU}_{\text{time}1} = 9.61 \text{ s}$$

$$\text{CPU}_{\text{time}2} = \left( \frac{2.56 \cdot 1}{2.07} + \frac{1.28 \cdot 12}{2.07} + 0.256 \cdot 5 \right) \cdot 10^9$$

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$$\text{CPU}_{\text{time}2} = 7,041$$

$$\text{CPU time 4} = \frac{cc}{C_P^2} = 3 \cdot 1,28 = 3,84$$

$$CC_3 = 10^9 \left( \frac{14 \cdot 1,28}{2,8} + ? \cdot 28 \right) = 10^9 \cdot 6 \cdot ? \cdot 28$$

$$b) \text{ speedup}_2 = \frac{\text{CPU time}_1}{\text{CPU time}_2} = 1,36$$

$$\text{speedup}_L = \frac{\text{CPL}_{\text{single}}^{-1}}{\text{CPL}_{\text{L}}^{-1}} = 2,5$$

$$\begin{aligned}
 \text{c) } \text{CPU}_{\text{time 1 now}} &= \frac{\text{Portion enhanced}}{\text{speed up}} + \text{Portion unenhanced} \\
 &= \frac{2,56 \cdot 10^9}{2 \cdot 10^9} + \frac{1,28 \cdot 10^9 \cdot (2+0,256 \cdot 10^9 \cdot 5)}{2 \cdot 10^9} \\
 &= \frac{2 \cdot 2,56 + 1,28 + 0,256}{2,56 + 1,28 + 0,256} = \frac{20 + 5 + 1}{10 + 5 + 1} = \frac{26}{16} = 1,625
 \end{aligned}$$

1.14, 1.15 + 1.9

**1.14** Assume a program requires the execution of  $50 \times 106$  FP instructions,  $110 \times 106$  INT instructions,  $80 \times 106$  L/S instructions, and  $16 \times 106$  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%?

$$CR = 2 \text{ GHz}$$

OP	CPI	IC
FP	1	$50 \times 106$
INT	1	$110 \times 106$
L/S	4	$80 \times 106$
B	2	$16 \times 106$

CPI for FP improve for 2x speedup

$$\text{CPU time } \text{sd} = \frac{\text{IC} \times \text{CPI} (=cc)}{\text{CR}} = \frac{54272}{2 \cdot 10^9} = 27 \cdot 10^{-6} \underline{27 \mu\text{s}}$$

$$\begin{aligned} CC &= 1 \times 50 \times 106 + 1 \times 110 \times 106 + 4 \times 80 \times 106 \\ &\quad + 2 \times 16 \times 106 = 106(50 + 110 + 320 + 32) \\ &= 54272 \end{aligned}$$

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

$$\text{CPU time new} = \frac{\text{CC new}}{\text{CR}}$$

$$\text{CC new} = \text{IC}_1 \times \text{CPI}_1 + \dots$$

$$= \text{IC}_{FP} \times \text{CPI}_{FP} + \text{IC}_{INV} \times \text{CPI}_{INV} + \dots$$

$$= 50 \times 106 \times \text{CPI}_{FP} + 110 \times 106 +$$

$$+ 4 \times 80 \times 106 + 2 \times 16 \times 106 =$$

$$= \underbrace{(50 \times \text{CPI}_{FP} + 110 + 320 + 32)}_{> 254} \times 106$$

$$\text{CC new} = \text{CR} \times \text{CPU time new} = 2.70 - 13,5 \cdot 10^{-6} = 27000$$

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

$\rightarrow x < 0 \rightarrow \text{Impossible}$

for CPI to be negative ✓

CPI for L/S for 2x speedup

$$\text{speedup} = \frac{\text{CPU time old}}{\text{new}} \Rightarrow$$

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

$$\begin{aligned}\text{CC}_{\text{new}} &= 1 \times 50 \times 10^6 + 110 \times 106 + \\ &+ \text{CPI}_{\text{L/S}}_{\text{new}} \times 80 \times 106 + 2 \times 16 \times 106 \\ &= 106 \left( 50 + 110 + \text{CPI}_{\text{L/S}}_{\text{new}} \times 80 + 32 \right)\end{aligned}$$

$$13,5 \cdot 10^{-6} = \frac{\text{CC}_{\text{new}}}{2 \cdot 10^9} \Rightarrow 27000 = 106 (192 + 80 \times \text{CPI})$$

$$192 + 80 \times \text{CPI}_{\text{L/S}}_{\text{new}} = 254,7$$

$$80 \times \text{CPI}_{\text{L/S}}_{\text{new}} = 62$$

$$\text{CPI}_{\text{L/S}}_{\text{new}} \approx 0,78$$

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

$CPI_{int}$  and  $F_P \rightarrow 40\%$   
 $CPI_{LS}$  and  $B_R \rightarrow 30\%$

Speedup = ?

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

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

$$CC_{new} = \frac{106}{100} \left( 50 \times 60 + 110 \times 60 + 320 \times 70 + 32 \times 70 \right)$$

$$CC_{new} = \frac{106}{100} \cdot 34240 = 36.294,4$$

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

$$\text{Speedup} = \frac{27}{18} \underset{\cancel{1,5}}{\sim} 1,5$$

**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).

$$\text{CPU time} = \text{Computing} + \text{Overhead}$$

$$t = 100 \text{ s}$$

$$\text{CPU time 1 Core}$$

$$t = 100 \text{ s}$$

$$P = 1$$

$$\sim t / P + 4 \text{ s (overhead)}$$

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  $0.7 \times p$  (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	CR = 2 GHz
ALU	1	$2.56 \cdot 10^9$	
L/S	12	$1.28 \cdot 10^9$	
B	5	$256 \cdot 10^6$	

$$P \text{ processors} \rightarrow \frac{IC_{ALU} + IC_{L/S}}{0.7 \times P}$$

$$\begin{aligned} CPU_{time 1} &= \frac{CC_1}{CR} = \frac{19.2 \cdot 10^9}{2 \cdot 10^9} = 9.6 \text{ s} \\ CC_1 &= 2.56 \cdot 10^9 + 12 \cdot 1.28 \cdot 10^9 + \underbrace{5 \cdot 256 \cdot 10^6}_{1.28 \cdot 10^9} \\ &= (2.56 + 15.36 + 1.28) \cdot 10^9 \\ &= 19.2 \cdot 10^9 \end{aligned}$$

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

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

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


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

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

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


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

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

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


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CPU P	CPU time	Relative Speedups
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?

$$CPU_{time\ 1\ new} = \frac{CC_1\ new}{CR}$$

$$CC_1\ new = \cancel{2 \cdot 2,56 \cdot 10^9} + 12 \cdot 1,28 \cdot 10^9 + 1,28 \cdot 10^9$$

$$\text{Speedup} = \frac{CPU_{time\ old}}{CPU_{time\ new}} = \frac{CC_1\ old}{CC_1\ new}$$

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

$$CC_1\ new = CC_4\ old$$

$$CC_1\ new = 2,56 \cdot 10^9 + CPI_{4S\ new} \cdot 1,28 \cdot 10^9 + 1,28 \cdot 10^9$$

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