# CSCI 2500 Homework 2 Written Portion

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## 1. Problem 1.5

P1: 3 GHz, CPI = 1.5
P2: 2.5 GHz, CPI = 1.0
P3: 4.0 GHz, CPI = 2.2

a) Clock rate = cycles/second, CPI = cycles/instruction
Instructions/s = Clock rate/CPI
P1: $3 * 10^9/1.5 = 2 * 10^9$ instructions/s
P2: $2.5 * 10^9/1.0 = 2.5 * 10^9$ instructions/s
P3: $4.0 * 10^9/2.2 = 1.82 * 10^9$ instructions/s
P2 has the highest instructions/s.

b) Instructions = instructions/s * time
P1: $2 * 10^9$ instructions/s * 10 seconds = $2 * 10^{10}$ instructions
P2: $2.5 * 10^9$ instructions/s * 10 seconds = $2.5 * 10^{10}$ instructions
P3: $1.82 * 10^9$ instructions/s * 10 seconds = $1.82 * 10^{10}$ instructions

Clock cycles = instruction count * CPI
P1: $2 * 10^{10}$ instructions * 1.5 CPI = $3 * 10^{10}$ cycles
P2: $2.5 * 10^{10}$ instructions * 1.0 CPI = $2.5 * 10^{10}$ cycles
P3: $1.82 * 10^{10}$ instructions * 2.2 CPI = $4.0 * 10^{10}$ cycles

c) CPU time = (instruction count * CPI)/clock rate
0.7*(CPU time) = (instruction count) * (1.2 * CPI))/(x * clock rate)
1.2/x = 0.7 so x = 1.71
Increase the clock rate by 71 percent.
P1: 1.71 * 3 GHz = 5.13 MHz
P2: 1.71 * 2.5 GHz = 4.28 GHz
P3: 1.71 * 4 GHz = 6.84 GHz

**2. Problem 1.7**

P1: 2.5 GHz; CPI of 1, 2, 3, 3 for classes A, B, C, D respectively
P2: 3 GHz; CPI of 2, 2, 2, 2 for classes A, B, C, D respectively
10 percent class A, 20 percent class B, 50 percent class C, 20 percent class D

a) CPI = $\sum_{i=1}^{n}(CPI_i * (relative\ frequency))$
$P1 : CPI = 1 * 0.1 + 2 * 0.2 + 3 * 0.5 + 3 * 0.2 = 2.6$
$P2 : CPI = 2 * 0.1 + 2 * 0.2 + 2 * 0.5 + 2 * 0.2 = 2$

$b$) Clock cycles = CPI * instruction count
Dynamic instruction count = 1 * $10^6$
P1: $2.6 * (1 * 10^6) = 2.6 * 10^6$ clock cycles
P2: $2 * (1 * 10^6) = 2 * 10^6$ clock cycles
CPU time = (Instruction Count * CPI)/clock rate
P1: $(1 * 10^6)(2.6)/(2.5\ GHz) = 1.04 * 10^{-3}$ s
P2: $(1 * 10^6)(2)/(3\ GHz) = 0.67 * 10^{-3}$ s
P2 is faster than P1

**3. Problem 1.8**

Compiler A: $1 * 10^9$ dynamic instructions, 1.1 seconds
Compiler B: $1.2 * 10^9$ dynamic instructions, 1.5 seconds

a) Processor clock time = 1 ns, CPU time = IC * CPI * Clock Cycle Time
CPI = CPU time / (IC * clock cycle time)
Compiler A: $1.1/(1 * 10^9 * 1 * 10^{-9}) = 1.1$ CPI
Compiler B: $1.5/(1.2 * 10^9 * 1 * 10^-9) = 1.25$ CPI

b) CPU time = (IC * CPI)/clock rate
We know CPU time is same for both compilers.
$1 * 10^9 * 1.1/clock\ rate\ A = 1.2 * 10^9 * 1.25/clock\ rate\ B$
Clock rate of processor for compiler B runs 1.37 times as fast as the clock of processor for compiler A

c) IC = $6 * 10^8, CPI = 1.1$
CPU time = IC * CPI/clock rate
Clock rate is processor dependent so it is the same for all compilers here (we will denote the clock rate in this problem by the variable a)
New compiler: $(6.0 * 10^8 * 1.1)/a$
Compiler A: $(1.0 * 10^9 * 1.1)/a$
Compiler B: $(1.2 * 10^9 * 1.25)/a$
A takes 1.67 times as long as the new compiler
B takes 2.27 times as long as the new compiler

**4. Problem 1.10**

a) CPU time = IC * CPI/clock rate
1 processor: $(1 * 2.56 * 10^9 + 12 * 1.28 * 10^9 + 5 * 2.56 * 10^8)/2$ GHz $= 9.6$ s
Relative speedup of 1 processor compared to 1 processor: $9.6/9.6 = 1$
2 processors: $(1 * 2.56 * 10^9/1.4 + 12 * 1.28 * 10^9/1.4 + 5 * 2.56 * 10^8)/2$ GHz $= 7.04$ s
Relative speedup of 2 processors compared to 1 processor: $9.6/7.04 = 1.36$
4 processors: $(1 * 2.56 * 10^9/2.8 + 12 * 1.28 * 10^9/2.8 + 5 * 2.56 * 10^8)/2$ GHz $= 3.84$ s
Relative speedup of 4 processors compared to 1 processor: $9.6/3.84 = 2.5$
8 processors: $(1 * 2.56 * 10^9/5.6 + 12 * 1.28 * 10^9/5.6 + 5 * 2.56 * 10^8)/2$ GHz $= 2.24$ s
Relative speedup of 8 processors compared to 1 processor: $9.6/2.24 = 4.29$

b) 1 processor: $(1 * 2.56 * 10^9 * 2 + 12 * 1.28 * 10^9 + 5 * 2.56 * 10^8)/2$ GHz $= 10.88$ s
2 processors: $(1 * 2.56 * 10^9 * 2/1.4 + 12 * 1.28 * 10^9/1.4 + 5 * 2.56 * 10^8)/2$ GHz $= 7.95$ s
4 processors: $(1 * 2.56 * 10^9 * 2/2.8 + 12 * 1.28 * 10^9/2.8 + 5 * 2.56 * 10^8)/2$ GHz $= 4.30$ s
8 processors: $(1 * 2.56 * 10^9 * 2/5.6 + 12 * 1.28 * 10^9/5.6 + 5 * 2.56 * 10^8)/2$ GHz $= 2.47$ s

c) 1 * 2.56 * $10^9 + 12 * 1.28 * 10^9 * a + 5 * 2.56 * 10^8 = 1.2 * 2.56 * 10^9/2.8 + 12 * 1.28 * 10^9/2.8 + 5 * 2.56 * 10^8$
$a = 0.25$
Reduce CPI of load/store instructions to 25 percent of the original value.

**5. Problem 1.13**

P1: 4 GHz, 0.9 CPI, $5 * 10^9$ instructions
P2: 3 GHz, 0.75 CPI, $1 * 10^9$ instructions

a) CPU time = IC * CPI/clock rate = $5 * 10^9 * 0.9/(4 * 10^9) = 1.125$ s
P2: $1 * 10^9 * 0.75/(3 * 10^9) = 0.25$ s
Performance = 1/CPU time
P1: $1/1.125 = 0.889$
P2: $1/0.25 = 4$
P2 performs better than P1, so a larger clock rate does not always mean better performance.

b) P1: $1 * 10^9$ instructions
CPU time = $1 * 10^9 * 0.9/(4 * 10^9) = 0.225$ s
IC = CPU time * Clock Rate/CPI = 0.225 * 3 * $10^9/0.75 = 9 * 10^8$ instructions that P2 can execute in 0.225 s

**6. Problem 1.15**

$50 * 10^6$ FP instructions, CPI $= 1$
$110 * 10^6$ INT instructions, CPI $= 1$
$80 * 10^6$ L/S instructions, CPI $= 4$
$16 * 10^6$ branch instructions, CPI $= 2$
2 GHz processor

a) CPU time = IC * CPI/Clock Rate
a * 50 * $10^6 * 1 + 110 * 10^6 * 1 + 80 * 10^6 * 4 + 16 * 10^6 * 2)/(2 * 10^9) = 0.5 * ((50 * 10^6 + 110 * 10^6 * 1 + 80 * 10^6 * 4 + 16 * 10^6 * 2)/(2 * 10^9))$
$a = -4.12$ so in this case the improvement that was asked for cannot be achieved

$b$) $(50 * 10^6 * 1 + 110 * 10^6 * 1 + 80 * 10^6 * 4 * a + 16 * 10^6 * 2)/(2 * 10^9) = 0.5((50 * 10^6 * 1 + 110 * 10^6 * 1 + 80 * 10^6 * 4 + 16 * 10^6 * 2)/(2 * 10^9))$
$a = 0.2$, Improve the CPI of L/S instructions by making it 20 percent of its original value.

$c$) Original: $(50 * 10^6 + 110 * 10^6 + 80 * 10^6 * 4 + 16 * 10^6 * 2)/(2 * 10^9) = 0.256\ s$
Improved: $(50 * 10^6 * 0.6 + 110 * 10^6 * 0.6 + 80 * 10^6 * 4 * 0.7 + 16 * 10^6 * 2 * 0.7)/(2 * 10^9) = 0.1712\ s$
$0.256/0.1712 = 1.495$
The improved program's execution time is 1.495 times faster than the original program.