ECE 4300 Homework 1

Ryan Schwartz

1.3) Describe the steps that transform a program written in a high-level language such as C into a representation that is directly executed by a computer processor.

**Once you have a program you want to run, you compile it. The compiler goes through each line of the program and executes the instruction for each line. If there is a problem with an execution, whether it be a syntax error or wrong operating system, the compiler will fail. After all of the instructions can be correctly executed, a binary file is generated by translating each line of code into the appropriate CPU binary instruction. Now that each line has been compiled into its corresponding binary instruction, the CPU can run the program using machine language.**

1.4) Assume a color display using 8 bits for each of the primary colors (red, green, blue) per pixel and a frame size of 1280 × 1024.

a. What is the minimum size in bytes of the frame buffer to store a frame?

Each color = 1 byte. 3 colors = 3 bytes. Therefore, (1280 x 1024) pixels x 3 bytes = **3,932,160 bytes.**

b. How long would it take, at a minimum, for the frame to be sent over a 100 Mbit/s network?

3,932,160 bytes = 31,457,260 bits. 31,457,260 / 100,000,000bits/sec = **.3145726 seconds**

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

a. Which processor has the highest performance expressed in instructions per second?

P1 = 3/1.5 = 2E9 IPS

P2 = 2.5/1 = 2.5E9 IPS = **P2 = highest IPS**

P3 = 4/2.2 = 1.8E9 IPS

b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions.

CPU time = 10 seconds, instructions = IPS \* CPU time, CPU time = clk cycles/clk rate

Clk cycles = CPU time \* clk rate

P1: 10s\*3Ghz = **30E9 cycles;** 2E9 IPS\*10s = **2E9 instructions**

P2: 10s\*2.5Ghz = **25E9 cycles;** 2.5E9 IPS\*10s = **25E9 instructions**

P3: 10s\*4Ghz = **40E9 cycles;** 1.8E9 IPS\*10s = **18E9 instructions**

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?

CPI / clk rate = 0.7 CPI / clk rate

1.2 CPI / clk rate = 0.7 CPI / clk rate

1.2 / clk rate = 0.7 / clk rate

Clk rate = 1.2/0.7 \* clk rate

1.2/0.7 = 1.7143

**71.43% increase from P1 (3Ghz), P2 (2.5Ghz), and P3 (4Ghz) clock rates:**

**P1: 5.14Ghz  
P2: 4.29Ghz  
P3: 6.86Ghz**

1.6) Consider two different implementations of the same instruction set architecture. Th e 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 implementation is faster?

Out of 1E6 instructions: A = E5, B = 2E5, C = 5E5, D = 2E5 instructions

CPU time = sum (CPI \* Ci) / clk rate

1\*A + 2\*B + 3\*C + 3\*D 2\*A + 2\*B + 2\*C + 2\*D

P1: sum of cycles with weights = 2.6E6

P2: sum of cycles with weights = 2E6

P1: CPU time = 2.6E6 / 2.5 GHz = 1.046 milliseconds

P2: CPU time = 2E6 / 3 GHz = .666 milliseconds

**P2 is faster**

1. What is the global CPI for each implementation?

P1: CPI = cycles / instructions = **2.6E6 / E6 = 2.6**

P2: CPI = cycles / instructions = **2E6 / E6 = 2**

b. Find the clock cycles required in both cases

**P1: sum of cycles with weights = 2.6E6**

**P2: sum of cycles with weights = 2E6**

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 results in a dynamic instruction count of 1.2E9 and an execution time of 1.5 s.

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

CPI = # cycles / #instructions = CPU time / (# instructions \* clk rate)

A: 1.1s / (1E9 \* 1E-9) = **1.1**

B: 1.5s / (1.2E9 \* 1E-9) = **1.25**

1. Assume the compiled programs run on two diff erent 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 = instructions \* CPI / clk rate

instructions \* CPI / clk rate = instructions \* CPI / clk rate

A should be slower since it is the same amount of time with less total instructions:

Clk rate A = (instructsA \* CPI)/( instructs \* CPI) \* clk rate B = 1E9 \* 1.1 / 1.2E9 \* 1.25 \* clk rate B = **.73**

**A is slower than B by 27%**

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?

CPU time = 6E8 \* 1.1 \* 1E-9 = 660 ms for new compiler C

**1.1s A / 660 ms C = 1.67**

**1.5s B / 660 ms C = 2.27**

**Therefore, C beats A by 67% and C beats B by 127%**

1.11) The results of the SPEC CPU2006 bzip2 benchmark running on an AMD Barcelona has an instruction count of 2.389E12, an execution time of 750 s, and a reference time of 9650 s.

1) Find the CPI if the clock cycle time is 0.333 ns

Cycles = 750s / .333E-9 = 2.25E12

CPI = cycles / instructions = 2.25E12 / 2.389E12

**CPI = .94**

2) Find the SPECratio

9650/750 = **12.87**

3) Find the increase in CPU time if the number of instructions of the benchmark is increased by 10% without aff ecting the CPI.

Instructions = 2.6279E12

CPU time = 2.6279E12 \* .94 \* .333E-9

**CPU time = 822.51 seconds**

4) Find the increase in CPU time if the number of instructions of the benchmark is increased by 10% and the CPI is increased by 5%.

Instructions = 2.6279E12

CPU time = 2.6279E12 \* .94 \* 1.05 \* .333E-9

**CPU time = 862.47 seconds**

5) Find the change in the SPECratio for this change

9650 / 862.47 = **11.19**

6) Suppose that we are developing a new version of the AMD Barcelona processor with a 4 GHz clock rate. We have added some additional instructions to the instruction set in such a way that the number of instructions has been reduced by 15%. Th e execution time is reduced to 700 s and the new SPECratio is 13.7. Find the new CPI.

CPI = cycles / instructions

Instructions = 2.03E12

Cycle time = 1/ clk rate = .25E-9

# of cycles = 700 / .25E-9 = 2.8E12

**CPI = 2.8E12 / 2.03E12 = 1.38**

7) Th is CPI value is larger than obtained in 1.11.1 as the clock rate was increased from 3 GHz to 4 GHz. Determine whether the increase in the CPI is similar to that of the clock rate. If they are dissimilar, why?

**As the clock rate increased, the CPI also increased because the total number of instructions had decreased. There were more cycles of the faster clock rate with less instructions than in 1.11.1.**

8) By how much has the CPU time been reduced?

700/750 = 0.933

**CPU time has decreased by about 7%.**

9) For a second benchmark, libquantum, assume an execution time of 960 ns, CPI of 1.61, and clock rate of 3 GHz. If the execution time is reduced by an additional 10% without aff ecting to the CPI and with a clock rate of 4 GHz, determine the number of instructions.

Instructions = (execution time \* clock rate) / CPI

Instructions = (864E-9 \* 4E9) / 1.61 = **2147 instructions**

10) Determine the clock rate required to give a further 10% reduction in CPU time while maintaining the number of instructions and with the CPI unchanged.

Clk rate = (CPI \* instructions) / execution time

Clk rate = (1.61 \* 2147) / (864E-9 \* .9) = **4.445 GHz**

11) Determine the clock rate if the CPI is reduced by 15% and the CPU time by 20% while the number of instructions is unchanged.

Clk rate = (CPI \* instructions) / execution time

Clk rate = (.85 \* 1.61 \* 2147) / (.8 \* 777.6E-9) = **4.72 GHz**

1.12) Section 1.10 cites as a pitfall the utilization of a subset of the performance equation as a performance metric. To illustrate this, consider the following two processors. P1 has a clock rate of 4 GHz, average CPI of 0.9, and requires the execution of 5.0E9 instructions. P2 has a clock rate of 3 GHz, an average CPI of 0.75, and requires the execution of 1.0E9 instructions

1) One usual fallacy is to consider the computer with the largest clock rate as having the largest performance. Check if this is true for P1 and P2.

CPU time = CPI \* instructions \* clk rate

P1: CPU time = 0.9 \* 5E9 \* (1/4 Ghz) = 1.125 seconds

P2: CPU time = 0.75 \* 1E9 \* (1/3 Ghz) **= .24975 seconds**

**P2 is faster.**

2) Another fallacy is to consider that the processor executing the largest number of instructions will need a larger CPU time. Considering that processor P1 is executing a sequence of 1.0E9 instructions and that the CPI of processors P1 and P2 do not change, determine the number of instructions that P2 can execute in the same time that P1 needs to execute 1.0E9 instructions.

CPI \* instructions \* clk rate = CPI \* instructions \* clk rate

0.9 \* 1E9 \* 0.25E-9 = 0.75 \* x \* 0.333E-9

**X = instructions = 9E8 instructions**

3) A common fallacy is to use MIPS (millions of instructions per second) to compare the performance of two diff erent processors, and consider that the processor with the largest MIPS has the largest performance. Check if this is true for P1 and P2.

MIPS = clk rate \* 10E-6 / CPI

P1: MIPS = 4E9 \* 10E-6 / 0.9 = 4.44E3

P2: MIPS = 3E9 \* 10E-6 / 0.75 = 4E3

**P1 has largest MIPS, P2 has faster execution time**

4) Another common performance fi gure is MFLOPS (millions of fl oating-point operations per second), defi ned as MFLOPS = No. FP operations / (execution time × 1E6) but this fi gure has the same problems as MIPS. Assume that 40% of the instructions executed on both P1 and P2 are fl oating-point instructions. Find the MFLOPS fi gures for the programs.

MFLOPS = # FPOs \* 10E-6 / execution time

P1: MFLOPS = 0.4 \* 10E-6 \* 5E9 / 1.125 = 1.78E3

P2: MFLOPS = 0.4 \* 10E-6 \* 1E9 / 0.25 = 1.60E3

**P1 has greater MFLOPS, but P2 still has greater performance**