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ECE 4300

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02/16/2022

Chapter 1: Problem 1.3, 1.4, 1.5, 1.6 , 1.7, 1.11, 1.12

1.3 [2] <§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.

Ans: The following steps are:

1. A complier will read the high-level source code of C and then translate it into a program in assembly language.
2. Then another program called an assembler will transform the program of the assembly language into a machine language program which in this case the computer processor will can understand and execute it.

1.4 [2] <§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 buff er to store a frame?
b. How long would it take, at a minimum, for the frame to be sent over a 100 Mbit/s network?

Ans:

(a) We know that 1 byte = 8 bits and we have each pixel using 8 bit each. Since there are 3 primary colors, one pixel will use up 3 bytes. The total pixels of the display is calculated to be $1280 \times 1024 = 1{,}310{,}720\ pixels$. The memory size of the frame would be $1{,}310{,}720\ pixels \times 3\ bytes = \mathbf{3{,}932{,}160\ bytes\ or\ 3.75MB}$

(b) First, we see that the speed for the frame to be sent over is 100 Mbit/s = 10^8 bit/s. Then we convert byte into bits again we will get $3{,}932{,}160\ bytes \times 8 = 31{,}457{,}280\ bits$. Finally, we calculate the $time = \frac{size}{speed} = \frac{31{,}457{,}280}{10^8} = \mathbf{0.3145s\ or\ 314.5ms}$

1.5 [4] <§1.6> 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?

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

Ans:

(a) To find the instruction per second or IPS we must derive it from the formula of CPU time which is shown as $CPU\ time = \frac{instructions \times CPI}{Clock\ Rate}$ we then change it to $IPS = \frac{instructions}{CPU\ time} = \frac{Clock\ Rate}{CPI}$. We know that 1 GHz = 10^9 Hz

P1 => IPS1 $= \frac{Clock\ Rate}{CPI} = \frac{3\ GHz}{1.5} = 2 \times 10^9$

P2 => IPS2 $= \frac{Clock\ Rate}{CPI} = \frac{2.5\ GHz}{1} = 2.5 \times 10^9$ ← Highest performance

P3 => IPS3 $= \frac{Clock\ Rate}{CPI} = \frac{4\ GHz}{2.2} = 1.82 \times 10^9$

(b) We know that the clock cycle is given by: $Clock\ Cycles = CPU\ Time \times Clock\ Rate$

We know that the instructions is also given by: $Instructions = IPS \times CPU\ time$

P1: $Instructions = IPS \times CPU\ time = 2 \times 10^9 \times 10\ \mathrm{sec} = 2 \times 10^{10}$

$Clock\ Cycles = CPU\ Time \times Clock\ Rate = 10\ sec \times 3 \times 10^9 = 3 \times 10^{10}$

P2: $Instructions = IPS \times CPU\ time = 2.5 \times 10^9 \times 10\ \mathrm{sec} = 2.5 \times 10^{10}$

$Clock\ Cycles = CPU\ Time \times Clock\ Rate = 10\ \mathrm{sec}\ 2.5 \times 10^9 = 2.5 \times 10^{10}$

P3: $Instructions = IPS \times CPU\ time = 1.82 \times 10^9 \times 10\ \mathrm{sec} = 1.82 \times 10^{10}$

$Clock\ Cycles = CPU\ Time \times Clock\ Rate = 10\ sec \times 4 \times 10^9 = 4 \times 10^{10}$

© $Execution\ Time = \frac{clock\ cycles}{clock\ rate}$

$clock\ cycles = instruction \times CPI$

Therefore:

$$Execution\ Time = \frac{instruction \times CPI}{clock\ rate}$$

In order to find the new clock we have to do the following formula:

$0.7 Execution\ Time(old) = Execution\ Time(new)$

$$0.7 \frac{instruction(old) \times CPI(old)}{clock\ rate(old)} = \frac{instruction(new) \times CPI(new)}{clock\ rate(new)}$$

Since Instruction do not change we can cancel it out:

$$0.7 \frac{CPI(old)}{clock\ rate(old)} = \frac{CPI(new)}{clock\ rate(new)}$$

The $CPI_{new} = 1.2 CPI_{old}$ we get:

$$\frac{0.7}{clock\ rate(old)} = \frac{1.2}{clock\ rate(new)}$$

$$clock\ rate(new) = \frac{1.2}{0.7} \times clock\ rate(old) = 1.71\ \times clock\ rate(old)$$

Therefore there need an increase of 71% of the clock rate.

1.6 [20] <§1.6> Consider two different implementations of the same instruction set architecture. The 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?
a. What is the global CPI for each implementation?
b. Find the clock cycles required in both cases.

Ans:

(a) The formula for CPU clock cycle is to be given by = $\sum_{i=1}^{n}(CPI_i) \times C_i$

For each different class we know that the program executes

$Class\ A = 10^6 \times 10\% = 10^6 \times 0.1 = 10^5\ instructions$

$Class\ B = 10^6 \times 20\% = 10^6 \times 0.2 = 2 \times 10^5\ instructions$

$Class\ C = 10^6 \times 50\% = 10^6 \times 0.5 = 5 \times 10^5\ instructions$

$Class\ D = 10^6 \times 20\% = 10^6 \times 0.2 = 2 \times 10^5\ instructions$

Let's find the CPU clock cycle for each Processors:

$CPU\ clock\ cycles\ P1 = (1 \times 10^5) + (2 \times 2 \times 10^5) + (3 \times 5 \times 10^5) + (3 \times 2 \times 10^5)$

$CPU\ clock\ cycles\ P1 = 2.6 \times 10^6$

$CPU\ clock\ cycles\ P2 = (2 \times 10^5) + (2 \times 2 \times 10^5) + (2 \times 5 \times 10^5) + (2 \times 2 \times 10^5)$

$CPU\ clock\ cycles\ P2 = 2 \times 10^6$

Finally, we find the Global CPI:

$$CPIp1 = \frac{CPU\ clock\ cycles\ P1}{Number\ of\ instrucitons} = \frac{2.6 \times 10^6}{10^6} = 2.6$$

$$CPIp2 = \frac{CPU\ clock\ cycles\ P2}{Number\ of\ instrucitons} = \frac{2 \times 10^6}{10^6} = 2$$

(b)

$CPU\ clock\ cycles\ P1 = (1 \times 10^5) + (2 \times 2 \times 10^5) + (3 \times 5 \times 10^5) + (3 \times 2 \times 10^5)$

$CPU\ clock\ cycles\ P1 = 2.6 \times 10^6$

$CPU\ clock\ cycles\ P2 = (2 \times 10^5) + (2 \times 2 \times 10^5) + (2 \times 5 \times 10^5) + (2 \times 2 \times 10^5)$

$CPU\ clock\ cycles\ P2 = 2 \times 10^6$

1.7 [15] <§1.6> 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.
b. Assume the compiled programs run on two different 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?
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?

Ans:

(a) To find the average CPI for each program, we need to use this formula

$$CPU\ time = instruction\ \times CPI \times Cycle\ Time$$

$$CPI = \frac{CPU\ time}{instructions \times cycle\ time}$$

$$CPI\ A = \frac{1.1\ s}{10^9 \times 10^{-9} s} = 1.1$$

$$CPI\ B = \frac{1.5\ s}{1.2\ \times 10^9 \times 10^{-9} s} = 1.25$$

(b) $Execution\ Time = CPU\ time = \frac{instruction\ \times CPI}{Clock\ rate}$

$$Execution\ Time\ A = Execution\ Time\ B$$

$$Clock\ RateA = \frac{instructionA\ \times CPIA}{instructionB\ \times CPIB} Clock\ RateB$$

$$Clock\ RateA = \frac{10^9\ \times 1.1}{1.2\ \times 10^9\ \times 1.25} Clock\ RateB$$

$$Clock\ RateA = \ 0.73\ Clock\ RateB$$

(c) CPU $Time_{new}$ = $instruction_{new}$ x CPI_{new} x cycle time

CPU Timenew$6 \times 10^8 \times 1.1 \times 10^{-9} = 0.66s$

Now we calculate the speed up ratio between each processor versus the new one

$$\frac{CPU\ Time\ A}{CPU\ Time\ C} = \frac{1.1s}{0.66s} = 1.67\ times$$

$$\frac{CPU\ Time\ B}{CPU\ Time\ C} = \frac{1.5s}{0.66s} = 2.27\ times$$

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.

1.11.1 [5] <§§1.6, 1.9> Find the CPI if the clock cycle time is 0.333 ns.
Ans:

$$CPU\ time = instruction\ \times CPI \times Cycle\ Time$$

$$CPI = \frac{CPU\ Time}{Instruction \times Cycle\ Time} = \frac{750s}{2.389 \times 10^{12} \times 0.333 \times 10^{-9}} = 0.942$$

1.11.2 [5] <§1.9> Find the SPECratio.
Ans:

$$SPEC\ ratio = \frac{Reference\ time}{Execution\ tIme} = \frac{9650}{750} = 12.87$$

1.11.3 [5] <§§1.6, 1.9> Find the increase in CPU time if the number of instructions of the benchmark is increased by 10% without affecting the CPI.
Ans:

We need to find the new CPU time. Let us first find the clock cycles

$$New\ number\ of\ instructions = \ 2.389 \times 10^{12}\ \times 1.1 = 2.6279 \times 10^{12}$$

$$Clock\ cycle = new\ number\ of\ instructions\ \times CPI$$

$$Clock\ cycle = 2.6279 \times 10^{12} \times 1.1 \times 0.942$$

$$Clock\ cycle = 2.47 \times 10^{12}$$

$$CPU\ time = Clock\ cycle\ \times Cycle\ Time$$

$$CPU\ time = 2.47 \times 10^{12}\ \times 0.333 \times 10^{-9}$$

$$CPU\ time = 822.51s$$

1.11.4 [5] <§§1.6, 1.9> 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%.
Ans:

Since the new CPI is increase by 5% we need to find the new CPI

Old CPI = 0.94

New CPI = 0.94 x 1.05 = 0.987

$$New\ Clock\ cycle = 0.987\ \times 2.6279 \times 10^{12}$$

$$New\ Clock\ cycle = 2.59 \times 10^{12}$$

$$CPU\ time = \ 2.59 \times 10^{12} \times 0.333 \times 10^{-9}$$

$$CPU\ time = \ 862.47\ s$$

1.11.5 [5] <§§1.6, 1.9> Find the change in the SPECratio for this change.

Ans:

$$SPEC\ ratio = \frac{Reference\ time}{Execution\ time} = \frac{9650}{862.47} = 11.19$$

1.11.6 [10] <§1.6> 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.

Ans:

Let us first fin the cycle time of this new processor:

$Cycle\ time = \frac{1}{clock\ rate} = \frac{1}{4\ GHz} = 0.25\ \times 10^{-9}s$

$Execution\ time = clock\ cycles\ \times Cycle\ time$

$clock\ cycles = \frac{Execution\ time}{Cycle\ Time} = \frac{700}{0.25\times10^{-9}} = 2.8 \times 10^{12}$

The new number of instruction is:

$new\ Instruction = 2.389 \times 10^{12} \times 0.85 = 2.03 \times 10^{12}$

$$new\ CPI = \frac{Clock\ Cycles}{Number\ of\ Instruction} = \frac{2.8 \times 10^{12}}{2.03 \times 10^{12}} = 1.38$$

1.11.7 [10] <§1.6> 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?

Ans:

$\frac{4}{3} = 1.333 < --\ clock\ rate\ ratio$

$\frac{1.38}{0.94} = 1.468 < --\ CPI\ ratio$

The results are not similar. This is because in 1.11.6 we have reduced the number of instructions.

1.11.8 [5] <§1.6> By how much has the CPU time been reduced?

Ans:

Old number of instructions: 750

New Number of instructions: 700

Ratio: $\frac{700}{750} = 0.933$

This shows that the CPU has decrease by at least 6.7%

1.11.9 [10] <§1.6> 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 affecting to the CPI and with a clock rate of 4 GHz, determine the number of instructions.

Ans:

$Execution\ time = clock\ cycles\ \times Cycle\ time$

$$Execution\ time = \frac{clock\ cycles}{clock\ rate}$$

$$Execution\ time = \frac{number\ of\ instructions\ \times CPI}{clock\ rate}$$

$$CPI = \frac{execution\ time \times clock\ rate}{number\ of\ instructions}$$
$$number\ of\ instructions = \frac{execution\ time \times clock\ rate}{CPI}$$
Since the execution time is reduce by 10%, the new execution time is:
$$new\ execution\ time = 0.9\ \times 960ns = 864 \times 10^{-9}s$$
$$number\ of\ instructions = \frac{864 \times 10^{-9} \times 4 \times 10^{9}}{1.61} = \mathbf{2147}$$

1.11.10 [10] <§1.6> 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.

Ans:

Clock rate is increase by 10%
$$864 \times 10^{-9} \times 0.9 = 777.6 \times 10^{-9}s$$
$$Clock\ rate = \frac{CPI\ \ \times Number\ of\ instructions}{execution\ time}$$
$$New\ Clock\ rate = \frac{1.61 \times 2147}{777.6 \times 10^{-9}s} = \mathbf{4.445\ GHz}$$

1.11.11 [10] <§1.6> Determine the clock rate if the CPI is reduced by 15% and the CPU time by 20% while the number of instructions is unchanged.

Ans:

Clock rate is reduced by 15%
$$1.61 \times 0.85 = 1.3685$$
$$Execution\ time = 777.6 \times 10^{-9}s\ \ \times 0.8 =\ 622.08 \times 10^{-9}s$$
$$Clock\ rate = \frac{CPI\ \ \times Number\ of\ instructions}{execution\ time}$$
$$New\ Clock\ rate = \frac{1.368 \times 2147}{622.08 \times 10^{-9}s} = \mathbf{4.72\ GHz}$$

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.

1.12.1 [5] <§§1.6, 1.10> 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.

Ans:

To check the performance we use the following formula

$$CPU\ time = \frac{instruction \times CPI}{Clock\ rate}$$

$$CPU\ time_{P1} = \frac{5 \times 10^9 \times 0.9}{4\ GHz} = \frac{4.5 \times 10^9}{3 \times 10^9} = 1.125s$$

$$CPU\ time_{P2} = \frac{1 \times 10^9 \times 0.75}{3\ GHz} = \frac{0.75 \times 10^9}{3\ \times 10^9} = 0.25s$$

Base on this on the comparison between CPU time of P1 and P2, it is clear that P2 have the better performance. Therefore having the largest clock rate does not determine the largest performance.

1.12.2 [10] <§§1.6, 1.10> 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.

Ans:

$$CPU\ time_{P1} = \frac{10^9 \times 0.9}{4\ GHz} = \frac{10^9 \times 0.9}{4 \times 10^9} = 0.225s$$

We need to find the number of instructions of with CPU time of P2 same as P1

$$0.225s = \frac{number\ of\ instructions_{p2} \times 0.75}{3 \times 10^9} =$$

$$number\ of\ instructions_{p2} = \frac{0.225s \times 3\ \times 10^9}{0.75} = 9 \times 10^8$$

Based on the aboved answer it shows that it is false that you need more CPU time to execute more instructions

1.12.3 [10] <§§1.6, 1.10> A common fallacy is to use MIPS (millions of instructions per second) to compare the performance of two different processors, and consider that the processor with the largest MIPS has the largest performance. Check if this is true for P1 and P2.

Ans:

$MIPS = \frac{clock\ rate}{CPI \times 10^6}$

$MIPS_{P1} = \frac{4 \times 10^9 Hz}{0.9 \times 10^6} = 4444$

$MIPS_{P2} = \frac{3 \times 10^9 Hz}{0.75 \times 10^6} = 4000$

Based on this answer, its shows that even though P1 have the bigger MIPS, it does not have the largest performance based on the answer of 1.12.1

1.12.4 [10] <§1.10> Another common performance figure is MFLOPS (millions of floating-point operations per second), defined as
MFLOPS = No. FP operations / (execution time × 1E6)
but this figure has the same problems as MIPS. Assume that 40% of the instructions executed on both P1 and P2 are floating-point instructions. Find the MFLOPS figures for the programs.

Ans:

We know that:

$$MFLOPS = \frac{FLOP\ instructions}{time \times 10^6} = \frac{0.4 \times instructions}{time \times 10^6} = 0.4MIPS$$

$$MFLOPS_{p1} = 1777.6$$

$$MFLOPS_{p2} = 1600$$