Homework Assignment 1

CS/ECE 3810: Computer Organization
Sept 02, 2020

Kyle Kazemini

Performance, Energy, and Power

Due Date: Sept 09, 2020.
(100 points)

Important Notes:

- Solutions turned in must be your own. Please, mention references (if any) at the end of each question. *Please refrain from cheating.*
- All solutions must be accompanied by the equations used/logic/intermediate steps. Writing only the final answer will receive **zero** credits.
- Partial score of every question is dedicated to each correct final answer provided by you. Please ensure both your equation/logic and final answer are correct. Moreover, you are expected to provide explanation for your solutions.
- All units must be mentioned wherever required.
- Late submissions **(after 11:59PM on 09/09/2020)** will not be accepted.
- We encourage all solutions to be typed in for which you could use software programs like LaTeX, Microsoft Word etc. If you submit handwritten solutions, they must be readable by the TAs to receive credits.
- All submitted solutions must be in the PDF format unless otherwise mentioned.

Power consumption. Designing processors performing tasks efficiently without dissipating excessive power is a significant challenge for CPU manufacturers. Power consumed by a processor is the sum of static power and dynamic power. Static power is the amount of power consumed by the computer when the system is idle. Dynamic power is the amount of power consumed by the computer while executing a task/program [Refer to Performance, Power, Energy Lecture Slide 29]

Question 1. In this problem, you will compute the static power and dynamic power of processor A. Processor A is operated in Turbo boost mode at a 4 GHZ clock frequency with a 1.1 V voltage supply. Suppose the average load capacitance of all the internal gates is 15pF. The static current driven from the supply is 1 Ampere and the logic gates exhibit an average activity of 0.5 per cycle.

i) Compute the static, dynamic, and total power consumed by Processor A. **(10 points)**

$Power_{static} = Voltage * Current_{static}$
$Power_{static} = 1.1\ V * 1\ Ampere = 1.1\ W$

$Power_{dynamic} = Capacitance * Voltage^2 * Activity * Frequency$
$Power_{dynamic} = 15\ pF * 1.1^2\ V * 0.5\ percycle * 4\ ps = 36.3\ W$

$Power_{total} = Power_{dynamic} + Power_{static}$
$Power_{total} = 1.1 + 36.3 = 37.4\ W$

ii) Compute the static, dynamic and total power consumed by Processor A, if the voltage is scaled up by 30% and the clock frequency is scaled down by 10%. **(10 points)**

$Power_{static} = Voltage * Current_{static}$
$Power_{static} = 1.43\ V * 1\ Ampere = 1.43\ W$

$Power_{dynamic} = Capacitance * Voltage^2 * Activity * Frequency$
$Power_{dynamic} = 15\ pF * 1.43^2\ V * 0.5\ percycle * 3.6\ ps = 55.2123\ W$

$Power_{total} = Power_{dynamic} + Power_{static}$
$Power_{total} = 1.43 + 55.2123 = 56.6423\ W$

Energy Consumption. Similar to power, the total energy consumed by a processor is the sum of static energy and dynamic energy. [Refer to Performance, Power, Energy slides 21-29]

Question 2. In this problem, we will compute the total energy consumed by a processor and will understand how it changes with the scaling of frequency and voltage. Assume that the processor consumes 70W of dynamic power and 20W of static power at 3GHz; and it completes a program in 20 seconds.

i) Compute the total energy (Dynamic and Static) consumed by the processor at 3 GHz. **(8 points)**

$Energy_{total} = (Power_{static} + Power_{dynamic}) * time$
$Energy_{total} = (20\ W + 70\ W) * 20\ sec = 1800\ kJ$

ii) Compute the total energy consumed (Dynamic and Static) by the processor, if the frequency scales down by 20% and the voltage scales up by 10%. **(12 points)**

New $Power_{static} = 22\ W$
New $Power_{dynamic} = 67.76\ W$
New $time = 24 sec$
$Energy_{total} = (22\ W + 67.76\ W) * 24\ sec = 2,154.24\ kJ$

Throughput. Throughput is a performance metric for computer systems. Broadly, it is defined as the total amount of work done in a given time. [Refer to Measuring performance Lecture slide 11 - 14]

To put it into perspective, if you have many programs to run, it is more beneficial to increase the number of programs running simultaneously instead of improving the response time or elapsed time of one particular job. This way, the overall time for completion of all the jobs will come down. In upcoming lectures, you will understand this more as all the modern processors employ pipelining to improve the throughput rather than the execution time of one particular task.

Question 3. In this problem, we will compute and compare the throughputs of two systems, A and B.

System A has two processors. Program X takes 60 seconds to execute on one of the processors. Program Y takes 60 seconds to execute in parallel to program X on the other processor.

System B has a single processor that can execute only one program at a time. Program X takes 35 seconds to run on this processor, and Program Y also takes 35 seconds.

Compute the throughput for both systems (A and B). Also, explain which system has a better throughput and why? **(20 points)**

System A finishes Program X and Program Y in 60 seconds. $\Rightarrow$ System A finishes each program in 30 seconds on average.

System B finishes Program X in 35 seconds and Program Y in 35 seconds. $\Rightarrow$ System B finishes each program in 35 seconds on average.

System A has a better throughput because it finishes the same amount of work (Program X and Program Y) 5 seconds faster on average and 10 seconds faster in total.

CPU execution time. CPU time is defined as the amount of time for which a CPU was used for processing instructions of a program. [Refer to Measuring performance lecture slide 18 - 19]

Question 4. In this problem, we will compare CPU times of two processors A and B. Compute speedup for the faster processor over the slower one. Consider Processor A has a clock cycle time of 25 ns and a CPI (cycles per instruction) of 2. Processor B has a clock cycle time of 50 ns and a CPI of 1.4. Both processors execute 100 billion instructions.

i) Compute the execution time for each processor (A and B). **(10 points)**

$CPUtime = IC * CPI * CT$
Processor A CPU time $= 100 * 10^9 * 2 * 2.5 * 10^{-8}\ sec = 5000\ sec\ or\ 83.33\ min.$
Processor B CPU time $= 100 * 10^9 * 1.4 * 5 * 10^{-8}\ sec = 7000\ sec\ or\ 116.66\ min.$

ii) Compute the speedup of the faster processor over the slower. **(10 points)**

Speedup = slower execution time / faster execution time

$\Rightarrow$ Speedup $= 7000\ sec\ /5000\ sec = 1.4x$
Therefore, Processor A is 1.4x faster than Processor B.

Question 5. In this question, we review different challenges affecting the performance of modern microprocessors.

i) How does Moore's law influence the processor performance in the past, present, and future? [Refer to Introduction and Logistics Lecture slide 23]**(10 points)**

Moore's Law (1965) states that transistor count doubles every year.
Moore's Law (1975) states that transistor count doubles every two years.
This law influences processor performance in the past greatly. As computers were being developed, transistor counts increased very rapidly.

As for the present, transistor counts are still increasing rapidly due to Moore's Law. Computers are becoming faster and faster every year, as transistor counts are doubling every two years.

As for the future, if Moore's Law continues to hold, computers will continue becoming exponentially faster like they have in the past and present.

ii) What is a Power wall ? How does it impact the growth of microprocessor performance? [Refer to chapter 1.7 in the textbook]**(10 points)**

"The 'Power Wall' refers to the difficulty of scaling the performance of computing chips and systems at historical levels, because of fundamental constraints imposed by affordable power delivery and dissipation."

Microprocessor performance is slowing down greatly because of the Power wall. Designers and architects are having to rethink the way microprocessors are built because of power leakage.

Bose, Pradip. "Power Wall." SpringerLink, Springer, Boston, MA, 1 Jan. 1970,
link.springer.com/referenceworkentry/10.1007/978-0-387-09766-$4_4$99.
