Homework Assignment 1

CS/ECE 6810: Computer Architecture

January 17, 2018

Performance Metrics

Due Date: 1/30/2018

(100 points)

1. **Summarizing Performance Numbers.** We ran four benchmark applications A, B, C, and D on a baseline computer system (BASE) and three newly proposed systems NEW1, NEW2, and NEW3. The execution time and system energy are measured as shown in the following tables.

Total Execution Time (s)				
	A	**B**	**C**	**D**
BASE	3	2.5	1	12
NEW1	7	3	5	1
NEW2	2	1	3	8
NEW3	1	3	2	13

System Energy (J)				
	A	**B**	**C**	**D**
BASE	20	40	50	15
NEW1	10	30	15	30
NEW2	30	60	20	20
NEW3	70	35	30	10

Assume that all of the applications are equally likely to be executed by users.

i. Which computer system results in the least execution time? **(10 points)**

Solution:

Arithmetic Mean (BASE) = (3 + 2.5 + 1 + 12) /4 = 4.625 s

Arithmetic Mean (NEW1) = (7 + 3 + 5 + 1) /4 = 4 s

Arithmetic Mean (NEW2) = (2 + 1 + 3 + 8) /4 = 3.5 s

Arithmetic Mean (NEW3) = (1 + 3 + 2 + 13) /4 = 4.75 s

Therefore, NEW2 computer system has the least execution time.

ii. Which computer system consumes the least energy? **(10 points)**
Solution:

Arithmetic Mean (BASE) = (20 + 40 + 50 + 15) /4 = 31.25 J
Arithmetic Mean (NEW1) = (10 + 30 + 15 + 30) /4 = 21.25 J
Arithmetic Mean (NEW2) = (30 + 60 + 20 + 20) /4 = 32.5 J
Arithmetic Mean (NEW3) = (70 + 35 + 30 + 10) /4 = 36.25 J

Therefore, NEW1 computer system consumes the least energy.

iii. Which computer system results in the least power consumption? **(10 points)**
Solution:

Power(W) = Energy(J) / Time(s)

Power (W)				
	A	**B**	**C**	**D**
BASE	6.67	16	50	1.25
NEW1	1.42	10	3	30
NEW2	15	60	6.67	2.5
NEW3	70	11.67	15	0.77

Arithmetic Mean (BASE) = (6.67 + 16 + 50 + 1.25) / 4 = 18.48 W
Arithmetic Mean (NEW1) = (1.42 + 10 + 3 + 30) / 4 = 11.105 W
Arithmetic Mean (NEW2) = (15 + 60 + 6.67 + 2.5) / 4 =21.0425 W
Arithmetic Mean (NEW3) = (70 + 11.67 + 15 + 0.77) / 4 = 24.36 W

Therefore, NEW1 computer system consumes the least power.

2. **Optimizing CPU Time.** The table below shows the frequencies and cycle counts for all types of instructions used by program A on a computer system P. We observed that 60% of the executed MULT instructions are followed by an ADD. Therefore, we propose a new processor with a

fused-MULT-ADD (FMAD) instruction that execute a merged MULT and ADD in 4 cycles.

	Load	Store	Branch	ADD	MULT
Frequency	**10%**	**5%**	**5%**	**30%**	**50%**
Cycles	**2**	**1**	**2**	**1**	**4**

i. Compute the instructions per cycle (IPC) for the new and old processors. **(10 Points)**

Solution:

For old processor:

Cycles per instruction (CPI) = (0.1*2) + (0.05*1) + (0.05*2)
+ (0.3*1) + (0.5*4)
= 2.65 cycles/instruction

Instructions per cycle (IPC) = 1/ CPI = 1/ 2.65 = 0.377 instrs/cycle

For new processor:

	Load	Store	Branch	ADD	MULT	FMAD
Frequency	**10%**	**5%**	**5%**	**0%**	**20%**	**30%**
Frequency (Normalized)	**14.28%**	**7.14%**	**7.14%**	**0%**	**28.57%**	**42.85%**
Cycles	**2**	**1**	**2**	**1**	**4**	**4**

Cycles per instruction (CPI) = (0.1428*2) + (0.0714*1) + (0.0714*2)
+ (0.2857*4) + (0.4285*4)
= 3.3566 cycles/instruction

Instructions per cycle (IPC) = 1/ CPI = 1/ 3.3566 = 0.2979 instrs/cycle

ii. What is the speedup/slowdown gained through the proposed optimization? **(10 Points)**

Solution:

Speedup = Old Execution time/ New execution time

$= (IC * CPI_{old} * CT) / (0.7IC * CPI_{new} * CT)$

= (1*2.65) / (0.7*3.3566)

= 1.12784

Therefore, there is a speedup of 12.78%.

3. **Amdahl's Law.** In a particular mobile device, 50% of the battery energy is consumed by a wireless interface, 20% in graphics and display units, 10% by the CPU, and 20% by other parts. Explain which one of the followings could be a better energy optimization. **(10 Points)**

Amdahl's Law interpreted for energy optimization:

$$\textbf{Energy}_{\text{overall}} = \text{Energy old / Energy new}$$

$$= \frac{1}{(1 - \text{Fraction}_{\text{enhanced}}) + (\text{Fraction}_{\text{enhanced}} / \text{Energy}_{\text{enhanced}})}$$

i. Reducing the wireless interface energy by 10%.

$$\textbf{Energy}_{\text{overall}} = \frac{1}{\mathbf{(1 - 0.5) + 0.5 / (1/0.9)}} = \mathbf{1.052}$$

i. Reducing the CPU energy by 60%.

$$\textbf{Energy}_{\text{overall}} = \frac{1}{\mathbf{(1 - 0.1) + 0.1 / (1/0.4)}} = \mathbf{1.0638}$$

ii. Reducing the display energy by 50%.

$$\textbf{Energy}_{\text{overall}} = \frac{1}{\mathbf{(1 - 0.2) + 0.2 / (1/0.5)}} = \mathbf{1.1111}$$

Therefore, Reducing the display energy by 50% is the best energy optimization as we have the most overall reduction of 1.111.

4. **Power and Energy.** Consider a general-purpose processor that operates at 2GHz and consumes 70W of dynamic power and 30W of static power. A particular application program requires 15 seconds to finish execution on this processor.
   i. Compute the energy consumed for executing the application. **(5 Points)**

      Solution:
      Energy = (Static Power + Dynamic Power) x Execution time
      = (30 W+ 70 W) x 15s = 1500 J
   ii. What is the energy consumption if the processor frequency scales down by 30%? **(5 Points)**

      Solution:
      Energy = (Static Power + Dynamic Power) x Execution time
      = (30 W+ 70 x 0.7 W) x (15/ 0.7) s = 1692.85 J

   iii. What is the energy consumption if both voltage and frequency scale down by 30%? **(10 Points)**

      Solution:
      Energy = (Static Power + Dynamic Power) x Execution time
      = (30 x 0.7 W+ 70 x $(0.7)^2$ x 0.7 W) x (15/ 0.7) s = 964.5 J

5. **Instruction Set Architecture.** Initial values of registers and memory are given below in the following tables. Compute the effective address and final result for each of the following instructions. All instructions are executed serially. Register value changes are considered when moving from one instruction to another. **(20 Points)**

```
LOAD R5, 6000(R0)

Effective address is 6000 + R0 = 6000 + 1000 =
7000
Result is R5 = 1

ADD R4, (R4)
Effective address is 6000, the value stored in
register R4.
```

Result is R4 = R4 + (R4)
= 6000 + 12
= 6012

SUB R2, R1
Effective address: N/A
Result is R2 = R2 - R1
= 99 - 25 = 74

LOAD R6, @(R0)
Effective address: 3000 (the value that is stored in memory address 1000)
Result is R6 = 33

ADD R6, R4
Effective address: N/A
Result is R6 = R6 + R4
= 33 + 6012 = 6045

SUB R5, R6
Effective address: N/A
Result is R5 = R5 - R6
= 1 - 6045 = -6044

ADD R2, R5
Effective address: N/A
Result is R2 = R2 + R5
= 74 - 6044 = -5970

ADD R2, (R3+R0)
Effective address: (4000 + 1000) = 5000
Result = R2 = R2 + 71 , where 71 is the value stored in address 5000
= -5970 + 71
= -5899