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EE488 - Computer Architecture
Homework Assignment #1

Due day: 5/25/2024

Instruction:

1. Push the answer sheet to Github in Word file.
2. Overdue homework submission could not be accepted.
3. Takes academic honesty and integrity seriously (Zero Tolerance of Cheating & Plagiarism)

Github repository: https://github.com/Chufeng-Jiang/SFBU-EE488-Computer-Architecture/tree/main/Homeworks/01_HW%20Assignment%231

1. Assuming that a web server with the architecture spends 20% on processing, 30% on disk access, and 50% on network transfer, you have a base system consisting of a 500MHz processor and a disk with 20Mbytes/sec data transfer rate. This system costs $5K and can support 10,000 average web page accesses/sec. Considering the following three options to enhance system performance:

    a. Option-1: replacing the existing disk with a disk supporting 40Mbytes/sec data transfer rate with an additional (compared to the base) cost of $1,000.

    b. Option-2: replacing the processor with an 800MHz processor with an additional (compared to the base) cost of $800.

    c. Option-3: using the two enhancements indicated in Option-1 & Option-2 together with an additional (compared to the base) cost of $1,500.

    (1) Determine what will be the new performance (in terms of average web page access per second) with each of the enhancement options.
    (2) By doing a cost-performance analysis, determine which option will be cost-effective to go for and why.

1.1 The Information for The Base System

Processor:	500 MHz
Disk:	20 Mbytes/sec
System Cost:	$5,000
Performance:	10,000 accesses/sec
Time spent:	Processing: 20%

	Disk access: 30% Network transfer: 50%

Let T to be the total time to serve one web page.

T_p = 0.2T
T_d = 0.3T
T_n = 0.5T
The time per access: T = $\frac{1}{10,000}$

Cost_0 per access = $\frac{5000}{10,000}$ = \$0.50/ accesses

1.2 New Performance for Each Access

1.2.1 Option-1: \$1,000 to improve disk (40 Mbytes/sec)

The new disk access time:

T_{dn} = $\frac{0.3\text{ T}}{40/20}$ = 0.15T
T_{n1} = 0.2T + 0.15T + 0.5T = 0.85T

Performance_1 = $\frac{1}{0.85\,T}$ = $\frac{1}{0.85 * \frac{1}{10,000}}$ = 11,764.71 accesses/sec

Cost_1 per access = $\frac{5000+1000}{11,764.71}$ = \$0.51/ accesses

1.2.2 Option-2: \$800to improve 800MHz processor

The new processor access time:

T_{pn} = $\frac{0.2\text{ T}}{800/500}$ = 0.125T
T_{n2} = 0.125T + 0.3T + 0.5T = 0.925T

Performance_2 = $\frac{1}{0.925\,T}$ = $\frac{1}{0.925 * \frac{1}{10,000}}$ = 10,810.81 accesses/sec

Cost_2 per access = $\frac{5000+800}{10,810.81}$ = \$0.54/ accesses

1.2.3 Option-3:
\$1,000 to improve disk (40 Mbytes/sec) + \$800to improve 800MHz processor

The new processor access time:

T_{dn}= $\frac{0.3\text{ T}}{40/20}$ = 0.15T
T_{pn} = $\frac{0.2\text{ T}}{800/500}$ = 0.125T
T_{n3}= 0.125T + 0.15T + 0.5T = 0.775T

$\text{Performance}_2 = \frac{1}{0.775\,T} = \frac{1}{0.775 * \frac{1}{10{,}000}}$ = 12,903.23 accesses/sec

Cost_2 per access = $\frac{5000+1500}{12{,}903.23}$ = \$0.5037 / accesses

1.3 Conclusion

1.3.1 Determine what will be the new performance

Options	Original	Option - 1	Option - 2	Option - 3
New Performance	10,000	11,764.71	10,810.81	12,903.23

1.3.2 Determine which option will be cost-effective to go for and why

Options	Original	Option - 1	Option - 2	Option - 3
New Performance	10,000	11,764.71	10,810.81	12,903.23
New Cost	\$0.50	\$0.51	\$0.54	\$0.5037

The base system and Option 3 almost have the same cost per access of \$0.50 per access/sec when rounding to 2 decimal points. However, Option 3 offers a higher performance (12,903.23 accesses/sec) compared to the base system (10,000 accesses/sec).

If the company has an extremely high visit frequency for the server OR the company does not have high profitability, keep the original one may be the most cost-effective enhancement. Otherwise, option 3 is the most cost-effective enhancement as it provides the maximum performance improvement with a minor increasing in the cost of \$0.0037 per access.

2. The Amdahl's law is based on the assumption that when an enhancement is performed to some part of the system, the enhancement doesn't have any negative impact on the non-enhanced part. However, in real life, it could lead to negative impact on these parts. Thus, Amdahl's law can be modified to take care of this situation.

   Consider a computer system with two components, A and B, which can be enhanced. There is interdependency between these components. And enhancement in one component affects the other. There are three options for enhancement as suggested below. All options involve the same amount of cost.

   a. Option-A: Let us assume that f_A, the fraction of instructions using component A, can be sped up by 10 times. However, due to the dependency of A on B, another fraction $2f_A$ will be get slowed down by 5 times.
   b. Option-B: The instructions using component B, fraction f_B, can be sped up by 20 times. The dependency forces another fraction $0.5f_B$ to get slow down by 2 times.
   c. Option-C: A fraction f_A of instructions using the component A, can be sped up by a factor of 4. Unfortunately, the dependency forces another fraction f_A to get slowed down by 1.8 times.

   (1) Derive the parameterized speed-up equations (in terms of f_A, f_B) for each of the above three options.

   (2) As a beginner architect, which option will be preferred and why? Give convincing reasoning. Assuming for a reasonable enhancement, you need to have $f_A > 0$ and $f_B > 0$

1.Derive the parameterized speed-up equations

1.1 Option-A:

$$\text{Speed} - \text{up}_A = \frac{1}{\frac{f_A}{10} + 5 * 2f_A + (\ 1 - f_A - 2f_A)}$$

$$= \frac{1}{7.1\ f_A + 1}$$

1.2 Option-B:

$$\text{Speed} - \text{up}_B = \frac{1}{\frac{f_B}{20} + 2 * 0.5f_B + (\ 1 - f_B - 0.5f_B)}$$

$$= \frac{1}{1 - \ 0.45\, f_B}$$

1.3 Option-C:

$$\text{Speed} - \text{up}_C = \frac{1}{\frac{f_A}{4} + 1.8 * f_A + (\, 1 - f_A - f_A)}$$

$$= \frac{1}{1 + 0.05\, f_A}$$

2.Which option will be preferred and why?

Since f_A is a non-negative value, $7.1f_A$ is always greater than $0.05f_A$, therefore $\frac{1}{7.1\, f_A+1}$ is always lower than $\frac{1}{1+0.05\, f_A}$. So, option C is better than option A.

Since f_B is a non-negative value, $1 - \ 0.45\, f_B$ is lower than 1, while $1 + 0.05\, f_A$ is greater than 1, therefore, $\frac{1}{1- \ 0.45\, f_B}$ is greater than $\frac{1}{1+0.05\, f_A}$. So, option B is better than option C.

In conclusion, I would prefer option B because it has the highest speed-up rate.

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3. A set of three systems are being evaluated to be used in a laboratory environment. This environment uses three types of programs with a relative usage of 45% (Program 1), 35% (Program 2), and 20% (Program 3) respectively. Each of these three programs has been benchmarked on these three systems individually and their execution times are shown as follows.

Programs	**System 1**	**System 2**	**System 3**
Programs 1	1.0 sec	2.0 sec	1.5 sec
Programs 2	10.0 sec	7.0 sec	5.0 sec
Programs 3	5.0 sec	3.0 sec	4.0 sec

a. Determine which of the above three systems will provide the best performance for the laboratory.

b. The three systems cost as follows: $8,000 (System 1), $5,000 (System 2), and $6,500 (System 3). By doing a cost-performance analysis, indicate which one of these systems you will choose and why.

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1. Determine which of the above three systems will provide the best performance for the laboratory

$$\text{Weighted Average Time}_{system} = T_{pro1} * U_{pro1} + T_{pro2} * U_{pro2} + T_{pro3} * U_{pro3}$$

1.1 System 1

$$\text{Weighted Average Time}_{system1} = 1 * 0.45 + 10 * 0.35 + 5 * 0.25$$
$$= 4.95\ sec$$

1.2 System 2

$$\text{Weighted Average Time}_{system2} = 2 * 0.45 + 7 * 0.35 + 3 * 0.25$$
$$= 3.95\ sec$$

1.3 System 3

$$\text{Weighted Average Time}_{system1} = 1.5 * 0.45 + 5 * 0.35 + 4 * 0.25$$
$$= 3.225\ sec$$

The system with the lowest weighted average execution time provides the best performance. Therefore, System 3 provides the best performance with an average execution time of 3.225 seconds.

2. Cost-performance analysis

$$\text{Cost Per Second} = \frac{Cost}{\text{Weighted Average Time}_{system}}$$

2.1 System 1

$$\text{Cost Per Second}_{system1} = \frac{\$8000}{4.95\ sec}$$

$$= \$1616.16\ per\ sec$$

2.2 System 2

$$\text{Cost Per Second}_{system2} = \frac{\$5000}{3.95\ sec}$$

$$= \$1265.82\ per\ sec$$

2.3 System 3

$$\text{Cost Per Second}_{system3} = \frac{\$6500}{3.225\ sec}$$

$$= \$2015.50\ per\ sec$$

In conclusion, system 2 has the lowest cost-performance ratio at $1265.82 per second, meaning it provides the best balance of cost and performance. Therefore, system 2 should be chosen based on the cost-performance analysis.