San Francisco Bay University

EE488 - Computer Architecture
Homework Assignment #1

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 a 20Mbytes/sec data transfer rate. This system costs $5K and can support 10,000 average web page accesses/sec. Consider 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: Replace 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 the new performance (in terms of average web page access per second) with each enhancement option.

   (2) By doing a cost-performance analysis, determine which option will be cost-effective and why.

⇨ The answer:

Given data:

Base system specs:

1) Processor = 500 MHZ
2) Disk Transfer Rate: 20 MB/S
3) Cost: $5000
4) Performance : 10,000 web page accesses/sec
5) Time distribution:
   i) Processing = 20%

ii) Disk Access = 30%

iii) Network Transfer = 50%

⇨ Option 1 : upgrading disk:

Disk Access fraction (f) = 30% (0.3)

Speedup factor (s) = $\frac{40\text{MB/s}}{20\text{MB/s}}$ = 2

New speedup (S) :

Using Amdahl's law :

$$\mathrm{S} = \frac{1}{(1-\mathrm{f}) + \frac{\mathrm{f}}{\mathrm{s}}}$$

Where,

S = speed up

F = fraction of execution time affected.

s = speedup factor

$$\mathrm{S} = \frac{1}{(1-0.3) + (\frac{0.3}{2})}$$
$$= \frac{1}{0.7 + 0.15}$$
$$= \frac{1}{0.85}$$
$$\approx 1.176$$

New Performance:

$$10{,}000 \times 1.176 = 11{,}760 \text{ accesses/sec}$$

⇨ Option 2 : upgrading processor:

Processing fraction (f) = 20% (0.2)

Speedup factor(s) = $\frac{800\text{MB/s}}{500\text{MB/s}}$ = 1.6

New speedup (S) :

Using Amdahl's law :

$$\mathrm{S} = \frac{1}{(1-\mathrm{f}) + \frac{\mathrm{f}}{\mathrm{s}}}$$

Where,

S = speed up

F = fraction of execution time affected.

s = speedup factor

$$S = \frac{1}{(1-0.2)+(\frac{0.2}{1.6})}$$
$$= \frac{1}{0.8+0.125}$$
$$= \frac{1}{0.925}$$
$$\approx 1.081$$

New Performance:

$$10{,}000 \times 1.081 = 10{,}810 \text{ accesses/sec}$$

⇨ Option 3: upgrading both

Now, calculating the combined speedup for processing (20%) and disk (30%).

Using Amdahl's law :

$$S = \frac{1}{\left(1-\left(f_{\text{processing}}+f_{\text{disk}}\right)\right)+\frac{f_{\text{processing}}}{s_{\text{processing}}}+\frac{f_{\text{disk}}}{s_{\text{disk}}}}$$

$$S = \frac{1}{\left(1-(0.2+0.3)\right)+\frac{0.2}{1.6}+\frac{0.3}{2}}$$
$$= \frac{1}{(1-0.5)+0.125+0.15}$$
$$= \frac{1}{0.5+0.125+0.15}$$
$$= \frac{1}{0.775}$$
$$\approx 1.29$$

New Performance:

$$10{,}000 \times 1.29 \approx 12{,}900 \text{ accesses/sec}$$

Cost – performance analysis

Option	Performance Increase	New Performance	Additional Cost ($)	Cost per 1,000 Accesses
Base	-	10,000	$5,000	$0.50

Option 1 (Disk)	1,760	11,760	$1,000	$0.57
Option 2 (Processor)	810	10,810	$800	$0.54
Option 3 (Both)	2,900	12,900	$1,500	$0.52

The option 3 is the best choice because it provides the highest performance improvement at the lowest cost per 1,000 web page accesses. While upgrading only the processor or disk offers some improvements, combining both upgrades results in the most significant performance boost. This reason makes Option 3 the most cost-effective the solution for enhancing system performance.

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 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 $f_B > 0$

⇨ The answer:

Using Amdahl's law:

$$S = \frac{1}{(1-f) + \frac{f}{s}}$$

Where,

S = speed up

F = fraction of execution time affected.

s = speedup factor

⇨ Option A:

Given :

Speedup on A (s) = A fraction f_A is speed up by $10x$.

Negative impact = Due to dependency, $2f_A$ slows down by $5x$.

Thus, the new execution time is:;

$$T' = (1 - f_A - 2f_A) + \frac{f_A}{10} + 2f_A \times 5$$

$$T' = (1 - 3f_A) + \frac{f_A}{10} + 10f_A$$

$$T' = 1 + 7.1f_A$$

Speed-up is:

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

⇨ Option – B : Enhancing B

Given:

Speedup on B = A fraction f_B is speed up by $20x$.

Negative impact = Due to dependency, $0.5f_B$ slows down by $2x$.
Now execution time:

$$T' = (1 - f_B - 0.5f_B) + \frac{f_B}{20} + 0.5f_B \times 2$$
$$T' = (1 - 1.5f_B) + \frac{f_B}{20} + f_B$$
$$T' = 1 - 0.5f_B + \frac{f_B}{20}$$
$$T' = 1 - 0.5f_B + 0.05f_B$$
$$T = 1 - 0.45f_B$$

Speed-up is:

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

⇨ Option C: Enhancing A

Given:

Speedup on A = A fraction A fraction f_A is speed up by $4x$.

Negative impact = Due to dependency, another f_A slows down by $1.8x$.

Thus, the new execution time is:

$$T' = (1 - f_A - f_A) + \frac{f_A}{4} + f_A \times 1.8$$
$$T' = (1 - 2f_A) + \frac{f_A}{4} + 1.8f_A$$
$$T' = (1 - 2f_A) + 0.25f_A + 1.8f_A$$
$$T' = 1 + 0.05f_A$$

Speed-up is:

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

⇨ The option B is the best because it provides the highest speed-up and minimizes the negative impact. Option B and C have too much slowdown, making them inefficient. As a beginner architect, I would recommend Option B because it delivers the best trade – off between speed-up and dependency effect.

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.

⇨ The answer:

Using Weighted Execution Time Calculation:

$$\text{Weighted Execution Time} = (T_1 \times W_1) + (T_2 \times W_2) + (T_3 \times W_3)$$

Where,

$T_1, T_2, T_3 =$ execution times of programs 1,2,and 3 on a given system.

$W_1, W_2, W_3 =$ weights

For our cases:

System 1:

$$W_1 = (1.0 \times 0.45) + (10.0 \times 0.35) + (5.0 \times 0.20)$$
$$= 0.45 + 3.5 + 1.0$$
$$= 4.95\ sec$$

System 2:

$$W_2 = (2.0 \times 0.45) + (7.0 \times 0.35) + (3.0 \times 0.20)$$

$$= 0.9 + 2.45 + 0.6$$
$$= 3.95\ sec$$

System 3:

$$W_3 = (1.5 \times 0.45) + (5.0 \times 0.35) + (4.0 \times 0.20)$$
$$= 0.675 + 1.75 + 0.8$$
$$= 3.225\ sec$$

Cost-Performance Analysis

$$\text{Cost per Performance} = \frac{\text{Cost of system}}{\text{weighted excution time}}$$

For system 1:

$$\frac{8000}{4.95} = \$1616.16$$

For system2:

$$\frac{5000}{3.95} = \$1265.82$$

For system 3:

$$\frac{6500}{3.225} = \$2015.50$$

The system with the lowest weighted execution time will provide the best overall performance for the laboratory. The best performance of system 3 with the lowest weighted execution time performs the best. It has balanced execution time across all three programs. Program 2 is the most time-consuming, and system 3 is faster.

The best system should not only perform well but also provide value for money. The cost per unit of performance is system 2 for best choice among system 1 and 3. System 2 has the lowest cost per performance ratio.