

## Solution of Exercise Sheet 1

### Exercise 1 (Different Client-Server Scenarios)

Company X runs 8,000 computer workplaces.

- Scenario 1: Fat clients (PC)
  - Electrical power rating per desktop: 400 watts
  - Electrical power rating per screen: 100 watts
- Scenario 2: Thin clients
  - Electrical power rating per thin client: 30 watts
  - Electrical power rating per screen: 100 watts
  - Electrical power rating per server blade: 400 watts
  - Each server blade has enough resources to run 40 virtual desktops

What are the electricity costs per year for 24/7 operation when the electricity price is 0,24 €/kWh?

*Scenario 1:*

*Electricity costs per year (including the leap year) for 8,000 computer workplaces:*

$$0.5 \text{ kW} * 24 \frac{\text{h}}{\text{Day}} * 365.25 \frac{\text{Day}}{\text{Year}} * 0.24 \frac{\text{€}}{\text{kWh}} * 8,000 = 8,415,360 \frac{\text{€}}{\text{Year}}$$

*Scenario 2:*

*Electricity costs per year (including the leap year) for 8,000 computer workplaces:*

$$0.13 \text{ kW} * 24 \frac{\text{h}}{\text{Day}} * 365.25 \frac{\text{Day}}{\text{Year}} * 0.24 \frac{\text{€}}{\text{kWh}} * 8,000 = 2,187,993.6 \frac{\text{€}}{\text{Year}}$$

*200 server blade are required to run the 8.000 computer workplaces.*

*Electricity costs per year (including the leap year) for 200 server blades.*

$$0.4 \text{ kW} * 24 \frac{\text{h}}{\text{Day}} * 365.25 \frac{\text{Day}}{\text{Year}} * 0.24 \frac{\text{€}}{\text{kWh}} * 200 = 168,307.2 \frac{\text{€}}{\text{Year}}$$

*Electricity costs per year for the computer workplaces and the server blades.*

$$2,187,883.6 \frac{\text{€}}{\text{Year}} + 168,307.2 \frac{\text{€}}{\text{Year}} = 2,356,190.8 \frac{\text{€}}{\text{Year}}$$

## Exercise 2 (Types of Clients)

Four types of clients exist in the client-server model. Describe the four types. Focus the differences.

- **X-Terminal** or **Text-Terminal**
  - Only display the (graphical) user interface and transfer the user interaction to the server
  - Calculation of the (graphical) user interface, data processing and data storage, data management are tasks of the server
- **Thin Clients** or **Zero Clients**
  - Calculate and display the graphical user interface
- **Applet Clients** or **Network Computers**
  - Calculate and display the graphical user interface and do a part of the data processing
  - The clients process the applications (applets) themselves
- **Fat Clients**
  - Only data management and data storage are located on the (file or database) server

## Exercise 3 (Storing and transmitting Data)

Common assumptions about data are:

- It is easy to store data today.
- It is easy to transport or transmit data today.

In this exercise, we verify the correctness of these statements.

1. A scientific experiment produces 15 PB of data per year, which need to be stored. What is the height of a stack of storage media, if for storing the data...
  - CDs (capacity: 600 MB =  $600 * 10^6$  Byte, thickness: 1.2 mm) are used?
  - DVDs (capacity: 4.3 GB =  $4.3 * 10^9$  Byte, thickness: 1.2 mm) are used?
  - Blu-rays (capacity: 25 GB =  $25 * 10^9$  Byte, thickness: 1.2 mm) are used?
  - HDDs (capacity: 2 TB =  $2 * 10^{12}$  Byte, thickness: 2.5 cm) are used?

**Attention: Calculate the solutions for both options:**

- 15 PB =  $15 * 10^{15}$  Byte  $\Leftarrow$  this way, the hardware manufacturer calculate
- 15 PB =  $15 * 2^{50}$  Byte  $\Leftarrow$  this way, the operating systems calculate

*Solution for CDs with 15 PB =  $15 * 10^{15}$  Byte:*

Number of CDs:  $\frac{15 * 10^{15} \text{ Byte}}{600 * 10^6 \text{ Byte}} = 25,000,000$

CD stack height:  $25,000,000 * 1.2 \text{ mm} = 30,000,000 \text{ mm}$   
 $= 3,000,000 \text{ cm}$   
 $= 30,000 \text{ m}$   
 $= 30 \text{ km}$

*Solution for CDs with 15 PB =  $15 * 2^{50}$  Byte:*

Number of CDs:  $\frac{15 * 2^{50} \text{ Byte}}{600 * 10^6 \text{ Byte}} = 28,147,498$

CD stack height:  $28,147,498 * 1.2 \text{ mm} = 33,776,997.6 \text{ mm}$   
 $= 3,377,699.76 \text{ cm}$   
 $= \text{approx. } 33,777 \text{ m}$   
 $= 33.78 \text{ km}$

*Solution for DVDs with 15 PB =  $15 * 10^{15}$  Byte:*

Number of DVDs:  $\frac{15 * 10^{15} \text{ Byte}}{4.3 * 10^9 \text{ Byte}} = 3,488,372.093$   
An integer number is required  $\implies 3,488,373$

DVD stack height:  $3,488,373 * 1.2 \text{ mm} = 4,186,047.6 \text{ mm}$   
 $= 418,604.76 \text{ cm}$   
 $= 4,186.0476 \text{ m}$   
 $= 4.1860476 \text{ km}$

*Solution for DVDs with 15 PB =  $15 * 2^{50}$  Byte:*

Number of DVDs:  $\frac{15 * 2^{50} \text{ Byte}}{4.3 * 10^9 \text{ Byte}} = 3,927,557.814$   
An integer number is required  $\implies 3,927,558$

DVD stack height:  $3,927,558 * 1.2 \text{ mm} = 4,713,069.6 \text{ mm}$   
 $= 471,306.96 \text{ cm}$   
 $= 4,713.0696 \text{ m}$   
 $= 4.7130696 \text{ km}$

*Solution for Blu-rays with 15 PB = 15 \* 10<sup>15</sup> Byte:*

Number of Blu-rays:  $\frac{15 \cdot 10^{15} \text{ Byte}}{25 \cdot 10^9 \text{ Byte}} = 600,000$

Blu-ray stack height:  $600,000 * 1.2 \text{ mm} = 720,000 \text{ mm}$   
 $= 72,000 \text{ cm}$   
 $= 720 \text{ m}$

*Solution for Blu-rays with 15 PB = 15 \* 2<sup>50</sup> Byte:*

Number of Blu-rays:  $\frac{15 \cdot 2^{50} \text{ Byte}}{25 \cdot 10^9 \text{ Byte}} = 675,539.944$   
An integer number is required  $\implies 675,540$

Blu-ray stack height:  $675,540 * 1.2 \text{ mm} = 810,648 \text{ mm}$   
 $= 81,064.8 \text{ cm}$   
 $= 810.648 \text{ m}$

*Solution for HDDs with 15 PB = 15 \* 10<sup>15</sup> Byte:*

Number of HDDs:  $\frac{15 \cdot 10^{15} \text{ Byte}}{2 \cdot 10^{12} \text{ Byte}} = 7,500$

HDD stack height:  $7,500 * 2.5 \text{ cm} = 18,750 \text{ cm}$   
 $= 187.5 \text{ m}$

*Solution for HDDs with 15 PB = 15 \* 2<sup>50</sup> Byte:*

Number of HDDs:  $\frac{15 \cdot 2^{50} \text{ Byte}}{2 \cdot 10^{12} \text{ Byte}} = 8,444.2493$   
An integer number is required  $\implies 8,445$

HDD stack height:  $8,445 * 2.5 \text{ cm} = 21,112.5 \text{ cm}$   
 $= 211.125 \text{ m}$

2. The data of the scientific experiment is transmitted via networks that use fiber-optic cables and provide a bandwidth of 40 Gbit/s.

- How long does it take to transfer the 15 PB via a 40 Gbit/s network?
- How long does it take to transfer the 15 PB via a 100 Mbps Ethernet?

**Attention: Calculate the solutions for both options:**

- 15 PB = 15 \* 10<sup>15</sup> Byte
- 15 PB = 15 \* 2<sup>50</sup> Byte

*Solution for the 40 Gbit/s network with 15 PB = 15 \* 10<sup>15</sup> Byte:*

40 Gbit/s bandwidth:  $40 \text{ Gbit/s} = 40,000,000,000 \text{ Bit/s}$   
 $= 5,000,000,000 \text{ Byte/s}$

Duration of transmission:  $\frac{15 \cdot 10^{15} \text{ Byte}}{5 \cdot 10^9 \text{ Byte/s}} = 3 \cdot 10^6 \text{ s} = 3,000,000 \text{ s}$   
 $= 50,000 \text{ m}$   
 $= 833.333333333 \text{ h}$   
 $= 34.722222222 \text{ d}$

⇒ approx. 34 Days, 17 Hours, 20 Minutes

*Solution for the 40 Gbit/s network with 15 PB = 15 \* 2<sup>50</sup> Byte:*

40 Gbit/s bandwidth:  $40 \text{ Gbit/s} = 40,000,000,000 \text{ Bit/s}$   
 $= 5,000,000,000 \text{ Byte/s}$

Duration of transmission:  $\frac{15 \cdot 2^{50} \text{ Byte}}{5 \cdot 10^9 \text{ Byte/s}} = 3,377,699.72 \text{ s}$   
 $= \text{approx. } 56,295 \text{ m}$   
 $= \text{approx. } 938.25 \text{ h}$   
 $= \text{approx. } 39.09 \text{ d}$

⇒ approx. 39 Days, 2 Hours, 15 Minutes

*Solution for the Ethernet network with 15 PB = 15 \* 10<sup>15</sup> Byte:*

Ethernet bandwidth:  $100 \text{ Mbit/s} = 100,000,000 \text{ Bit/s}$   
 $= 12,500,000 \text{ Byte/s}$

Duration of transmission:  $\frac{15 \cdot 10^{15} \text{ Byte}}{12,500,000 \text{ Byte/s}} = 1,200,000,000 \text{ s}$   
 $= 20,000,000 \text{ m}$   
 $= 333,333.3333 \text{ h}$   
 $= 13,888.88889 \text{ d}$   
 $= 38.02570538 \text{ y}$

⇒ approx. 38 Years, 13 Days, 21 Hours, 20 Minutes

*Solution for the Ethernet network with 15 PB = 15 \* 2<sup>50</sup> Byte:*

Ethernet bandwidth:  $100 \text{ Mbit/s} = 100,000,000 \text{ Bit/s}$   
 $= 12,500,000 \text{ Byte/s}$

Duration of transmission:  $\frac{15 \cdot 2^{50} \text{ Byte}}{12,500,000 \text{ Byte/s}} = 1,351,079,888 \text{ s}$   
 $= 22,517,998.13 \text{ m}$   
 $= 375,299.9688 \text{ h}$   
 $= 15,637.4987 \text{ d}$   
 $= 42.81313812 \text{ y}$   
*(each year has 365,25 days!)*

$\Rightarrow$  approx. 42 Years, 296 Days, ...

## Exercise 4 (Laws and Limitations)

1. What is the central statement of Moore's law?

*The number of transistors per area unit on an integrated circuit doubles every 24 months.*

2. What is the Von Neumann bottleneck?

*Each additional CPU decreases the relative performance gain.*

3. How can the Von Neumann bottleneck be weakened?

*Caches reduce the bottleneck impact.*

4. What is the central statement of Amdahl's law?

*The performance gain, when executing a programs in parallel on multiple CPUs is limited mainly by the sequential part of the problem.*

5. Which important factor is ignored by Amdahl's law?

*Amdahl's law does not take into account the cache and the effects, which are caused by the cache in practice. A growing number of CPUs also increases the quantity of fast memory which is available.*

6. What is the central statement of Gustafson's law (highlight the difference against Amdahl's law)?

*The bigger a parallelizable problem is, the smaller is the portion of the sequential part. A problem, which is sufficiently large, can be parallelized efficiently. The sequential part is not limiting, because it gets more and more unimportant as the number of CPUs rises.*

## Exercise 5 (Parallel Computers)

1. Describe the shared memory architecture in just a few words.

*In systems with shared memory, the entire memory is part of a uniform address space, which is accessed by all CPUs.*

2. Name two challenges of shared memory architectures.

*Write operations of the CPUs must be coordinated.*

*Data inside the CPU caches. If a memory cell duplicated in multiple CPU caches, any change in the memory cell must be propagated to all caches.*

3. What is the difference between asymmetric and symmetric multiprocessing (SMP)?

*Symmetric multiprocessing (SMP) allows to dynamically distribute the running processes to all available CPUs.*

*In asymmetric multiprocessing systems, each CPU must be assigned to a fixed task. One or more CPUs run the operating system. The other processes are distributed to the remaining CPUs.*

4. Give an example for a system in practice which implements the asymmetric multiprocessing architecture.

*the IBM Cell processor.*

5. Give an example for a system which implements the symmetric multiprocessing (SMP) architecture.

*Dual-Mainboards which are used often in Workstations or Server systems.*

6. Describe the distributed memory architecture in just a few words.

*In systems with distributed memory, each CPU can only access its own local memory.*

7. Name a drawback of distributed memory architectures.

*Network connections are much slower, compared with the data rate between CPU and memory.*