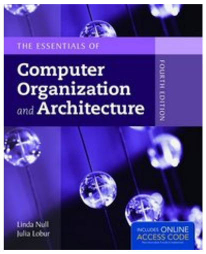

The Essentials of Computer Organization and Architecture
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Linda Null and Julia Lobur
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Chapter 7 Instructor's Manual

Chapter Objectives

Chapter 7, Input/Output and Storage Systems, provides a detailed overview of I/O fundamentals (including interrupt handling), bus communication and protocols, and typical external storage devices, such as magnetic and optical disks, as well as the various formats available for each. DMA, programmed I/O, and interrupts are covered as well. In addition, various techniques for exchanging information between devices are introduced. RAID architectures are covered in detail. Various data compression formats are introduced in the Focus on Data Compression section.

This is a very large chapter, but instructors need not lecture on all topics. This was written with the intention of students reading the material. Many of the topics (such as disk layouts and logical formats) can easily be read and understood by the student. In addition, some material is more FYI in nature. However, there are some topics which should be covered in lecture. Lectures over the material in Chapter 7 should focus on the following points:

- **Amdahl's Law.** This law characterizes the interrelationship of the components within the system. Understanding the speedup potential in a system is particularly important for the concepts in Chapter 10, Performance.
- **I/O architectures.** I/O control methods (programmed I/O, interrupt-driven I/O, DMA, and channel I/O) and I/O bus operation are important topics in helping students understand the system as a whole.
- **RAID.** RAID devices allow for redundancy (in different ways) in storing data, thus offering improved performance and increased availability for systems employing these devices. Levels 0 through 6, in addition to some hybrid systems, are introduced.
- **Data compression (optional).** Data compression not only helps economize on disk usage, but it reduces transmission time in data communications as well. This section contains

some mathematically challenging concepts and should probably not be left for the student to read on his or her own.

An instructor could also lecture over sections 7.6 (Magnetic Disk Technology), 7.7 (Optical Disks), and 7.8 (Magnetic Tape). However, these sections are easily read by the student.

Required Lecture Time

The important concepts in Chapter 7 can typically be covered in 2 lecture hours. However, if a teacher wants the students to have a mastery of all topics in Chapter 7, 6 lecture hours are more reasonable.

Lecture Tips

Students often have difficulty understanding the importance and application of Amdahl's Law. Going over several examples (perhaps looking ahead to Chapter 11) can help motivate the study of this law. *Please note: if something has a speedup of 2 (2 times), then the percentage improvement is 100%.* For example, a speedup of 1.5 means a 50% increase. A speedup of 1 would mean no improvement.

It is important to be specific about the differences among the I/O control methods. In particular, instructors should focus on interrupt-driven I/O and how it differs from DMA, as both involve interrupts.

Some of the RAID levels are theoretical and have not been deployed, and this should be pointed out in lecture. While covering these levels, the advantages and disadvantages of each should be covered, in addition to situations in which one level is better or worse than another.

Answers to Exercises

♦ 1. Calculate the overall speedup of a system that spends 65% of its time on I/O with a disk upgrade that provides for 50% greater throughput.

Ans.

1.28 or 28% ($S = 1.2766$; $f = 0.65$; $k = 1.5$)

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2. Calculate the overall speedup of a system that spends 40% of its time in calculations with a processor upgrade that provides for 100% greater throughput.

Ans.

1.25 or 25% (S = 1.25; f = 0.4; k = 2)

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3. Suppose your company has decided that it needs to make certain busy servers 50% faster. Processes in the workload spend 60% of their time using the CPU and 40% on I/O. In order to achieve an overall system speedup of 25%:

a) How much faster does the CPU need to be?
b) How much faster does the disk need to be?

Ans.

a) The CPU needs to be 50% faster: S = 1.25; f = 0.6; k=1.25/((1/1.25)-(1-0.6)) = 1.5
b) The disk needs to be 100% faster: S = 1.25; f = 0.4; k=1.25/((1/1.25)-(1-0.4)) = 2

---

4. Suppose your company has decided that it needs to make certain busy servers 30% faster. Processes in the workload spend 70% of their time using the CPU and 30% on I/O. In order to achieve an overall system speedup of 30%:

a) How much faster does the CPU need to be?
b) How much faster does the disk need to be?

Ans

a) The CPU needs to be 49.18% faster: S = 1.30; f = 0.7; k=1.3/((1/1.3)-(1-0.7)) = 1.4918
b) The disk needs to be 333% faster: S = 1.25; f = 0.3; k=0.3/((1/1.3)-(1-0.3)) = 4.33333

---

5. Suppose that you are designing a game system that responds to players' pressing buttons and toggling joysticks. The prototype system is failing to react in time to these input events, causing noticeable annoyance to the gamers. You have calculated that you need to improve overall system performance by 50%. This is to say that the entire system needs to be 50% faster than it is now. You know that these I/O events account for 75% of the system workload. You figure that a new I/O interface card should do the trick. If the system's existing I/O card runs at 10 kHz (pulses per second), what is the speed of the I/O card that you need to order from the supplier?

Ans.

At least 18kHz. (S needs to be 1.5; f = 0.75; k = 1.8)

---

6. Suppose that you are designing an electronic musical instrument. The prototype system occasionally produces off-key notes, causing listeners to wince and grimace. You have determined the cause of the problem is that the system becomes overwhelmed in

processing the complicated input. You are thinking that if you could boost overall system performance by 12% (making it 12% faster than it is now), you could eliminate the problem. One option is to use a faster processor. If the processor accounts for 25% of the workload of this system, and you need to boost performance by 12%, how much faster does the new processor need to be?

Ans.

At least 75% faster. (S needs to be 1.12; f = 0.25; k = 1.75.)

---

7. Your friend has just bought a new personal computer. She tells you that her new system runs at 1GHz, which makes it over three times faster than her old 300 MHz system. What would you tell her? (Hint: Consider how Amdahl's Law applies.)

Ans.

You would explain Amdahl's Law. The processor is only one component contributing to the overall performance of a system.

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8. Suppose the daytime processing load consists of 60% CPU activity and 40% disk activity. Your customers are complaining that the system is slow. After doing some research, you have learned that you can upgrade your disks for $8,000 to make them 2.5 times as fast as they are currently. You have also learned that you can upgrade your CPU to make it 1.4 as fast for $5,000.

   a) Which would you choose to yield the best performance improvement for the least amount of money?
   b) Which option would you choose if you don't care about the money, but want a faster system?
   c) What is the break-even point for the upgrades? That is, what price would we need to charge for the CPU (or the disk – change only one) so the result was the same cost per 1% increase for both?

Ans.

Fraction of work: 60% CPU, 40% disk.

S_{CPU} = 1/((1-f)+(f/k)) = 1/((1-0.60)+(0.60/1.4)) = 1.2069 or 20.69%

S_{DISK}= 1/((1-f)+(f/k)) = 1/((1-0.40)+(0.40/2.5)) = 1.3158 or 31.58%

a) Choose the CPU upgrade:
   CPU = $5000/20.69% = $241.66 per 1% increase in performance
   Disk = $8000/31.58% = $253.32 per 1% increase in performance
b) The disk option gives a better performance improvement.

c) We want the price per 1% to be the same. If we change the CPU price, we have X/20.69 = 253.32, and X= $5241. This means if the CPU costs $5241, we break even on cost per 1% improvement. If we change the price of the disk, we have Y/31.58 = 241.66, Y= 7631.

♦9. How would you answer exercise 8 if the system activity consists of 55% processor time and 45% disk activity?

Ans.

Fraction of work: 55% CPU, 45% disk.
S_{CPU} = 1/((1-f)+(f/k)) = 1/((1-0.55)+(0.55/1.4)) = 1.1864 or 18.64%
S_{DISK}= 1/((1-f)+(f/k)) = 1/((1-0.45)+(0.45/2.5)) = 1.3699 or 36.99%

a) Choose the disk upgrade:
CPU = $5000/18.64% = $268.24 per 1% increase in performance
Disk = $8000/36.99% = $216.27 per 1% increase in performance

b) The disk upgrade gives the greater improvement: 36.99% versus 18.64% for the processor.

c) We want the price per 1% to be the same. If we change the price of the CPU, we have X/18.64 = 216.27, or X= $4031. If we change the price of the disk, we have Y/36.99 = 268.24, or Y = $9922.

---

10. Amdahl's Law is as applicable to software as it is to hardware. An oft-cited programming truism states that a program spends 90% of its time executing 10% of its code. Thus, tuning a small amount of program code can often time have an enormous affect on the overall performance of a software product. Determine the overall system speedup if:
a) 90% of a program is made to run 10 times as fast (900% faster).
b) 80% of a program is made to run 20% faster.

Ans.

a) S = 5.26 (425%) (f = 0.9; k = 10)
b) S = 1.15 (15%) (f = 0.8; k = 1.2)

---

11. Name the four types of I/O architectures. Where are each of these typically used and why are they used there?

Ans.

1. Programmed I/O – good for control applications, e.g., sensors
2. Interrupt-driven I/O – used in personal systems
3. DMA – good for small to medium-sized systems
4. Channel I/O – used in the largest enterprise-class systems

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♦12. A CPU with interrupt-driven I/O is busy servicing a disk request. While the CPU is midway through the disk-service routine, another I/O interrupt occurs.

♦a) What happens next?
♦b) Is it a problem?
♦c) If not, why not? If so, what can be done about it?

Ans.

a) A CPU should disable all interrupts before it enters an interrupt service routine, so the interrupt shouldn't happen in the first place.
b) It is a problem.
c) If interrupts are disabled, the second interrupt would never happen so it is not a problem.

Alternative good answer:

a) The CPU could save all information from the interrupt service routine that it was working on, just as if it were a user program.
b) Could be a problem.
c) Information coming from multiple sources at the same time could get garbled. The best thing to do is to disable all maskable interrupts while I/O is occurring.)

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13. A generic DMA controller consists of the following components:

- Address generator
- Address bus interface
- Data bus interface
- Bus requestor
- Interrupt signal circuits
- Local peripheral controller.

The local peripheral controller is the circuitry that the DMA uses to select among the peripherals connected to it. This circuit is activated right after the bus is requested. What is the purpose of each of the other components listed above and when are they active? (Use Figure 7.6 as a guide.)

Ans.

1. The address generator is the second component (in our list) activated. (The first is the interrupt signal circuits.) The address generator determines which address lines need to be activated to effect the transfer.
2. The address bus interface is used by the address generator to place the source or destination address on the address bus. It is the fourth component activated.
3. The data bus interface is the fifth component activated. It receives the bytes that the DMA pulls from memory or a peripheral device.
4. The bus requester is the third component activated. It places a control signal on the "Bus request" control line if the bus is busy. The bus requester then waits for a "bus

grant" signal before signaling the DMA to commence the transfer. It also raises the bus grant signal during another arbitration exchange.

5. The interrupt signal circuits pass and receive interrupt signals to the CPU and peripherals. It is the first and last DMA component set activated during a transfer.

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14. Of programmed I/O, interrupt-driven I/O, DMA, or channel I/O, which is not suitable for processing the I/O of a:

    a) Mouse
    b) Game controller
    c) CD
    d) Thumb drive or memory stick

    Explain your answers.

Ans.

Mice and game controllers are character-based, sequential devices. Either programmed I/O or interrupt-driven I/O is best. CDs and thumb drives are block-oriented devices that lend themselves to DMA. Channel I/O is suitable, but excessive for the small amount of data involved.

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15. Why are I/O buses provided with clock signals?

Ans.

Bus clocks maintain synchronization and define bit cell boundaries.

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16. If an address bus needs to be able to address eight devices, how many conductors will be required? What if each of those devices also needs to be able to talk back to the I/O control device?

Ans.

Three conductors will be needed. To provide bidirectionality, either we add three more conductors for the other direction or add a single control line that indicated the “direction” of the signal on the other three.

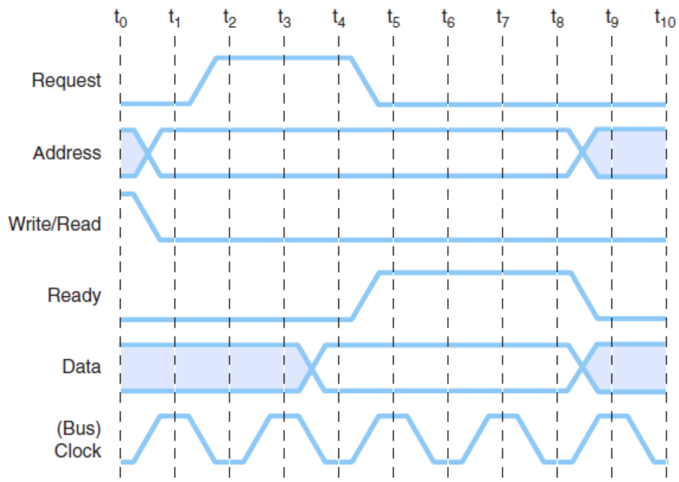
---

17. The protocol for a certain data bus is shown in the table below. Draw the corresponding timing diagram. You may refer to Figure 7.11.

Time	Salient Bus Signal	Meaning
t_0	Assert Read	Bus is needed for reading (not writing)
t_1	Assert Address	Indicates where bytes will be written
t_2	Assert Request	Request read to address on address lines
$t_{3\text{ - }}t_7$	Data lines	Read data (requires several cycles)
t_4	Assert Ready	Acknowledges read request, bytes placed on data lines.
t_4	Lower Request	Request signal no longer needed.
t_8	Lower Ready	Release bus

Ans.

In comparison to Figure 7.11, we observe that the read/write line is lowered at t_0 and Ready is asserted only after the data lines are stable.



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18. With regard to Figure 7.11 and Problem 17 above, we have not provided for any type of error handling, such as if the address on the address lines were invalid, or the memory couldn't be read owing to a hardware error. What could we do with our bus model to provide for such events?

Ans.

The most direct approach would be to include a separate line just for error conditions. This signal could be asserted by controllers on either the source or the destination ends of the data transfer. Alternatively, we might just fail to raise the Ready signal and reassert the Request signal.

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19. We pointed out that I/O buses do not need separate address lines. Construct a timing diagram similar to Figure 7.11 that describes the handshake between an I/O controller and a disk controller for a write operation. (Hint: You will need to add a control signal.)

Ans.

Note: The control signal can be either “error” or “ack.”

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* 20. If each interval shown in Figure 7.11 is 50 nanoseconds, how long would it take to transfer 10 bytes of data? Devise a bus protocol, using as many control lines as you need, that would reduce the time required for this transfer to take place? What happens if the address lines are eliminated and the data bus is used for addressing instead? (An additional control line may be needed.)

Ans.

Four time slots to set up the transfer ⇒ 50 * 4 = 200ns
Ten timeslots to transfer the data ⇒ 50 * 10 = 500ns
One timeslot to tear down transfer ⇒ 50ns.
Total time = 200ns + 500ns + 50ns = 750ns.

---

21. Define the terms seek time, rotational delay, and transfer time. Explain their relationship.

Ans.

Seek time is the time it takes for a disk arm to position itself over a requested track. Rotational delay is the time that it takes for the required sector to position itself under a read/write head. The sum of the rotational delay and seek time is known as the access time. If we add to the access time the time that it takes to actually read the data from the disk, we get transfer time.

♦22. Why do you think the term random access device is something of a misnomer for disk drives?

Ans.

Some people think that retrieving specific data from a particular disk is not a "random" act.

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23. Why do differing systems place disk directories in different track locations on the disk? What are the advantages of using each location that you cited?

Ans.

Some systems place the directory in the center of the disk for faster access time. Others place it on the outer tracks because the medium has fewer errors there. Outer track directory placement provides greater data integrity (less error recovery), but does not, in general, perform as well as center disk placement.

♦24. Verify the average latency rate cited in the disk specification of Figure 7.15. Why is the calculation divided by 2?

Ans.

7200rpm = 120 rev/sec = 0.008333 sec/rev = 8.333ms per revolution. (Alternatively, 60,000ms per minute/7200 revolutions per minute = 8.333ms per revolution.) The average is half of this, or 4.17ms.

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25. By inspection of the disk specification in Figure 7.15, what can you say about whether the disk drive uses zoned-bit recording?

Ans.

The disk does not provide zoned-bit recording because the number of sectors per track is fixed.

---

26. The disk specification in Figure 7.15 gives a data transfer rate of 60MB per second when reading from the disk, and 320MB per second when writing to the disk. Why are these numbers different? (Hint: Think about buffering.)

Ans.

Disk writes are buffered.

---

27. Do you trust disk drive MTTF figures? Explain.

Ans.

MTTF is a theoretical, statistical calculation with a tentative relationship to reality. MTTF methodologies can vary from vendor to vendor, so they are of limited use for making comparisons unless the methodology is mandated—such as in a government contract.]

♦28. Suppose a disk drive has the following characteristics:

- 4 surfaces
- 1024 tracks per surface
- 128 sectors per track
- 512 bytes/sector
- Track-to-track seek time of 5 milliseconds
- Rotational speed of 5000 RPM.

♦a) What is the capacity of the drive?
♦b) What is the access time?

Ans.

a) 4 surfaces x 1,024 tracks per surface $\times$ 128 sectors per track $\times$ 512 bytes/sector = $4 \times 1024 \times 128 \times 512/(2^{20}$ bytes/MB) = 256MB.

b) Rotational delay = (60 seconds/5000 rpm) × (1000ms/second)]/2 = 6 ms + 5ms seek time = 11 ms.

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29. Suppose a disk drive has the following characteristics:
    - 5 surfaces
    - 1024 tracks per surface
    - 256 sectors per track
    - 512 bytes/sector
    - Track-to-track seek time of 8 milliseconds
    - Rotational speed of 7500 RPM.

    a) What is the capacity of the drive?
    b) What is the access time?
    c) Is this disk faster than the one described in question 17? Explain.

Ans.

a) 5 surfaces x 1,024 tracks per surface × 256 sectors per track × 512 bytes/sector = 5×1024×256×512/(2^20 bytes/MB) = 640MB.
b) Rotational delay = (60 seconds/7500 rpm) × (1000ms/second)]/2 = 4ms + 8ms seek time = 12ms.
c) The track-to-track seek time makes it slower.

---

30. Suppose a disk drive has the following characteristics:
    - 6 surfaces
    - 16,383 tracks per surface
    - 63 sectors per track
    - 512 bytes/sector
    - Tract-to-track seek time of 8.5 milliseconds
    - Rotational speed of 7,200 RPM.

    a) What is the capacity of the drive?
    b) What is the access time?

Ans.

a) 6 surfaces × 16,383 tracks / surface × 63 sectors / track × 512 bytes/ sector = 1,585,350,144 bytes or 1.5TB
b) Access time = rotational delay + seek time; Rotational delay (latency) =(60/7200) × 1000)/2; Access time = ((60/7200) × 1000)/2 = 4.17ms + 8.5ms = 12.67ms

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31. Suppose a disk drive has the following characteristics:

- 6 surfaces
- 953 tracks per surface
- 256 sectors per track
- 512 bytes/sector
- Tract-to-track seek time of 6.5 milliseconds
- Rotational speed of 5,400 RPM.

a) What is the capacity of the drive?
b) What is the access time?
c) Is this disk faster than the one described in Question 26? Explain.

Ans.

a) 6 surfaces $\times$ 953 tracks / surface $\times$ 256 sectors / track $\times$ 512 bytes/ sector = 749,469,696 bytes or 750MB
b) Access time = rotational delay + seek time; Rotational delay (latency) =(60/5400) $\times$ 1000)/2; Access time = ((60/5400) $\times$ 1000)/2 = 5.56ms + 6.5ms = 12.05ms.
c) No, this disk is slower than the disk in Question 29. This disk is only 95% as fast as the disk in Question 29: 12.05 / 12.67 = 0.95107.

♦32. Transfer rate of a disk drive can be no faster than the bit density (bits / track) times the rotational speed of the disk. Figure 7.15 gives a data transfer rate of 112 GB/sec. Assume that the average track length of the disk is 5.5 inches. What is the average bit density of the disk?

Ans.

93 MB/track

Bit density = Transfer rate ÷ Rotational speed

where rotational speed is (7200 RPM / 60) = 120 rev/sec ;

Bit density = 112 GB/sec ÷ (120 rev/sec) = 93 MB/track

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33. What are the advantages and disadvantages of having a small number of sectors per disk cluster? (Hint: You may want to think about retrieval time and the required lifetime of the archives.)

Ans.

The advantage with a smaller number of sectors per cluster, is that you get more efficient usage (less wasted space) on the disk. The disadvantage is that the disk directory (or FAT) gets very large and may slow things down.

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34. How does the organization of an optical disk differ from the organization of a magnetic disk?

Ans.

Optical disks are fundamentally sequential media, whereas magnetic disks are direct (or random). Also, a magnetic disk directory is in a fixed location on the medium, on CDs, directory entries can “float.”

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35. How does the organization of an SSD differ from a magnetic disc? How are they similar to a disk?

Ans.

An SSD consists of memory, thus, data is access via address lines, just like memory instead of via a read-write head mounted on a disk arm. SSDs, particularly the NAND variety, are similar to magnetic disks because they are accessed in chunks: pages and sectors, respectively.

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36. In Section 7.6.2, we said that magnetic disks are power hungry as compared to main memory. Why do you think this is the case?

Ans.

A magnetic disk has a number of mechanical parts. Energy is needed to make the parts move, and a good deal of this energy is dissipated in the form of heat—especially in the bearings of the disk drive.

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37. Explain wear leveling and why it is needed for SSDs. We said that wear-leveling is important for the continual updating of virtual memory pagefiles. What problem does wear-leveling aggravate for pagefiles?

Ans.

Wear leveling is a technique that ensures an even distribution of erase-update cycles on an SSD system. Using wear-leveling an updated data block almost never occupies the same block as the original. Because pagefiles require a great deal of storage (usually twice the size of main memory), pagefile fragmentation can become a problem on an SSD.

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38. Compare the disk specifications for the HDD and SSD in Figures 7.15 and 7.16 respectively. Which items are the same? Why? Which items are different? Why?

Ans:

Any item having to do with a rotating platter will not appear in the SSD specification. Specifically: Buffer size, platters, data surfaces, tracks per surface, track density, recording density, sectors per track, start/stop cycles, rotational speed, and spin-up. All other items are relevant to any data storage medium.

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39. If 800GB server-grade HDDs cost $300, electricity costs $0.10 per kilowatt hour, and facilities cost $0.01 per GB per month, use the disk specification in Figure 7.15 determine how much it costs to store 8TB of data online for 5 years. Assume that the HDD is active 25% of the time. What can be done to reduce this cost? Hint: Use the "Read/Write" and "Idle" power requirements in Figure 7.15.

Ans:

Specifications	
Hours/year	8,760
Cost per kWh	0.1
Active percentage	0.25
Active watts	14.4
Idle percentage	0.75
Idle watts	9.77

Hours active/yr	0.25 × 8,760 = 2,190	
KWatts consumed active	2,190 × 14.4 ÷ 1,000	= 31.536
Hours idle/yr	0.75 × 8,760 = 6,570	
KWatts consumed idle	6,570 × 9.77 ÷ 1,000	= 64.1889
	Total KW	95.7249
	Energy cost / yr	$9.57
	× 5 disks	$47.85
	× 5 years	$239.25
	+ disk costs $300 × 10	$3,239.25

Facilities	
Fixed cost per GB per month	0.01
Number of GB	× 8000
Total cost per month	= 80
Number of months	× 60
Total facilities cost	$4,800.00

Grand total:	$8,039.25

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40. The disk drives connected to the servers in your company's server farm are nearing the end of their useful life. Management is considering replacing 8TB of disk capacity with SSDs. Someone is making the argument that the difference in the cost between the SSDs and traditional magnetic disks will be offset by the cost of electricity saved by the SSDs. The 800GB SSDs cost $900. The 800GB server-grade HDDs cost $300. Use the disk specifications in Figures 7.15 and 7.16 to confirm or refute this claim. Assume that both the HDD and SSD are active 25% of the time and that the cost of electricity is $0.10 per kilowatt hour. Hint: Use the "Read/Write" and "Idle" power requirements in Figure 7.15.

Ans.

Over the 5-year lifetime of the disks, an SSD will consume $6.62 in electricity while an HDD will consume $47.86. While much more costly to operate (even without considering cooling costs) the total cost of ownership of the HDD is still much less than the SSD. That being said, the impact on the environment—i.e., the energy consumption—is non-trivial, especially for a large server farm. In this case, spending more money is probably the right thing to do. Besides, I/O performance will improve!

Calculations:
SSD

Hours/year	8760					
Cost per kWh	0.1					
Active percent	0.25	Hours active/yr		2190		
Active watts	5	KWatts consumed active			10.95	
Idle percent	0.75	Hours idle/yr		6570		
Idle watts	0.35	KWatts consumed idle			2.2995	
			Total KW		13.2495	
			Cost		$1.32	per year per disk
HDD					$6.62	5-year costs

Hours/year	8760					
Cost per kWh	0.1					
Active percent	0.25	Hours active/yr		2190		
Active watts	14.4	KWatts consumed active			31.536	
Idle percent	0.75	Hours idle/yr		6570		
Idle watts	9.77	KWatts consumed idle			64.1889	
			Total KW		95.7249	
			Cost		$9.57	per year per disk
					$47.86	5-year costs

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41. A company that has engaged in a business that requires fast response time has just received a bid for a new system that includes much more storage than was specified in the requirements document. When the company questioned the vendor about the increased storage, the vendor said that he was bidding a set of the smallest capacity disk drives that the company makes. Why didn't the vendor just bid fewer disks?

Ans.

The key idea is performance. The vendor calculated throughput based on the number of disk arms. The greater number of disk arms, the better the I/O response time. Having fewer disks would cause I/O delays because transactions would have to compete for fewer disk arms.

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42. Discuss the difference between how DLT and DAT record data. Why would you say that one is better than the other?

Ans.

DLT uses serpentine recording while DAT uses helical scan. DAT is more complicated to implement than DLT. DAT puts more wear on the tape and is generally less reliable than DLT. Many implementations of DLT record data faster than DAT.

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43. How would the error-correction requirements of an optical document storage system differ from the error-correction requirements of the same information stored in textual form? What are the advantages offered by having different levels or error correction for optical storage devices?

Ans.

A document image will tolerate single-bit errors. Text storage will not. By eliminating error-correcting codes from the stored data, we can store more data on a disk and access it faster.

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44. You have a need to archive a large amount of data. You are trying to decide whether to use tape or optical storage methods. What are the characteristics of this data and how it is used that will influence your decision?

Ans.

How near-line does it have to be? (What kind of access times do the users require?) How long and where will the archive volumes be stored? Is the data in some coded form like ASCII or EBCDIC, or is it binary like scanned images? Does backup time matter? Price?

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45. Discuss the pros and cons of using disk versus tape for backups.

Ans.

Refer to the sidebar on Pages 363 - 364. In general, tape is best suited for long-term archival storage of data, and disk is best suited for quick recovery. With tape, the storage of multiple generations of data is possible. That is, you may have a set of monthly backups that you rotate over a year. Specifically, the June 2006 backup is written over the June 2005 tapes. It is fallacious to say categorically that disk backup is faster than tape. Using compression, and the most modern tape equipment, tape is faster than disk to write the backup. Disk may be faster for retrieval, however, because disk is a direct access device.

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46. Suppose you have a 100GB database housed on a disk array that supports a transfer rate of 60MBps and a tape drive that supports 200GB cartridges with a transfer rate of 80MB per second. How long will it take to back up the database? What is the transfer time if 2:1 compression is possible?

Ans.

Assuming that the tape is mounted and no errors occur, the backup can be completed in: 100GB/60MBps ≈ 1,667 seconds or approximately 1/2 hour. Compression will make no difference because the bottleneck is the disk transfer speed. Compression takes place at the tape drive, and the data has to be read from disk-- at 60MBps-- before it can get to the tape head for 2:1compression.

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* 47. A particular high-performance computer system has been functioning as an e-business server on the Web. This system supports $10,000 per hour in gross business volume. It has been estimated that the net profit per hour is $1,200. In other words, if the system goes down, the company will lose $1,200 every hour until repairs are made. Furthermore, any data on the damaged disk would be lost. Some of this data could be retrieved from the previous night's backups, but the rest would be gone forever. Conceivably, a poorly-timed disk crash could cost your company hundreds of thousands of dollars in immediate revenue loss, and untold thousands in permanent business loss. The fact that this system is not using any type of RAID is disturbing to you.

Although your chief concern is data integrity and system availability, others in your group are obsessed with system performance. They feel that more revenue would be lost in the long run if the system slows down after RAID is installed. They have stated specifically that a system with RAID performing at half the speed of the current system would result in gross revenue dollars per hour declining to $5,000 per hour.

In total, 80% of the system e-business activity involves a database transaction. The database transactions consist of 60% reads and 40% writes. On average, disk access time is 20ms.

The disks on this system are nearly full and are nearing the end of their expected life, so new ones must be ordered soon. You feel that this is a good time to try to install RAID, even though you'll need to buy extra disks. The disks that are suitable for your system cost $2000 for each 10 gigabyte spindle. The average access time of these new disks is 15ms with a MTTF of 20,000 hours and a MTTR of 4 hours. You have projected that you will need 60 gigabytes of storage to accommodate the existing data as well as the expected data growth over the next 5 years. (All of the disks will be replaced.)

a) Are the people who are against adding RAID to the system correct in their assertion that 50% slower disks will result in revenues declining to $5,000 per hour? Justify your answer.
b) What would be the average disk access time on your system if you decide to use RAID-1?
c) What would be the average disk access time on your system using a RAID-5 array with two sets of 4 disks if 25% of the database transactions must wait behind one transaction for the disk to become free?
d) Which configuration has a better cost-justification, RAID-1 or RAID-5? Explain your answer.

Ans.

a) No. Only 80% of the system activity involves the database. Proportionately then, doubling the disk access time would affect only 80% of the system activity. Access time would still be a lot slower according to their thinking:

(Percent of transaction on disk * half of the throughput) + (Percent of transaction in CPU * 10,000) = (0.8 * 0.5 * 10,000) + (0.2 * 10,000) = 4000 + 2000 = $6,000 per hour. So, using their assumptions, revenues would decline by only $4,000 not $5,000!

b) In RAID-1, it takes twice as long to do a write as a read, because data has to be written twice. However, access time for a read is half of what we would expect from a system not using RAID-1, assuming that the disk arms are 180 degrees offset from one another. Average Access Time = 0.4 * (15 ms / 2) + 0.6 * (15 ms * 2) = 21 ms.]

c) Average Access Time = 0.75 * 15ms + 0.25 * 30ms = 18.75 ms.]

d) Both RAID solutions will offer database response time comparable to what is currently offered by the system. The RAID-1 system will require 2*N disks while the 4-disk RAID-5 solution will require 133% of the number of disks. That is, RAID-1 will cost $24,000 and RAID-5 will cost $16,000. The cost of the disks isn't the big issue here, however. What matters most is system availability. With 8 disks each with a MTTF of 20,000 hours, we can expect a failure of at least two of the disks to fail within 20,000/8 hours, or 2,500 hours. So at least twice a year, we could expect a disk failure that will last 4 hours. If RAID-1 is used, the system will continue to function, while the RAID-5 system will be down, costing roughly $4,800 in lost revenue during each outage. (No data would be lost, though!)

Cost of RAID-1: $24,000; Cost of RAID-5: $16,000 + $9,600 revenue loss = $25,600.

The RAID-1 is therefore more economical. Note: We have not included loss of goodwill and permanent business loss in the RAID-5 figure. This tilts the balance greatly in favor of the RAID-1 solution.]

---

48. a) Which of the RAID systems described in this chapter cannot tolerate a single disk failure?
b) Which can tolerate more than one simultaneous disk failure?

Ans.

a) RAID-0.

b) RAID-1, RAID-2 and RAID-6. RAID-1 can tolerate multiple disk failures only if the failure does not involve a disk and its mirror image.

---

49. Our discussion of RAID is biased toward consideration of standard rotating magnetic disks. Is RAID necessary for SSD storage? If not, does this make SSD storage slightly more affordable for the enterprise? If it is necessary, do the redundant disks necessarily need to also be SSD?

Ans.

The idea of RAID for SSD storage, certainly lays to rest the use of "inexpensive" for the I in the RAID acronym! That being said, there are still risks of failure for SSDs just as there are for HDDs. Sectors can wear out and become unusable. Errant electric fields can destroy an entire SSD in milliseconds.

Yes, if you are going to use RAID, all of the disks must be alike, whether they are SSDs or HDDs.

Chapter 7A: Focus On Data Compression

1. Who was the founder of the science of information theory? During which decade did he do his work?

Ans.

Claude Shannon is considered by most authorities to be the father of information theory. He started his work in the late 1940s.

---

2. What is information entropy and how does it relate to information redundancy?

Ans.

Entropy is the measure of information content in a message. The greater the entropy of a message, the more information it contains. If a message contains a great deal of redundant information, it will have low entropy.

---

3. a) Name two types of statistical coding.
   b) Name an advantage and a disadvantage of statistical coding.

Ans.

a) The statistical coding types discussed in the text are: Huffman coding, and arithmetic coding.
b) The main advantage of statistical coding is that it can provide nearly optimal compression. The main disadvantage is that two passes over the message are required.

---

4. Use arithmetic coding to compress your name. Can you get it back after you have compressed it?

Ans.

The reader should follow the algorithm given on Pages 392 through 395. The correctness of this exercise will be shown when the reader can encode and decode his name.

---

5. Compute the compression factors for each of the JPEG images in Figure 7A.4.

Ans.

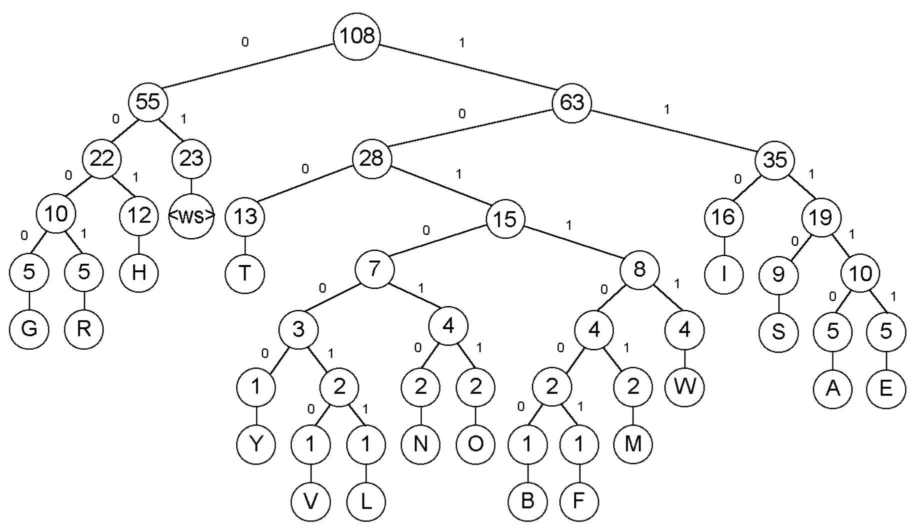
a) 1-(5.33/7.14) * 100% = 25.35%
b) 1-(1.96/7.14) * 100% = 72.55%
c) 1-(1.49/7.14) * 100% = 79.13%
d) 1-(1.11/7.14) * 100% = 84.45%
e) 1-(0.639/7.14) * 100% = 91.05%
f.) 1-(0.556/7.14) * 100% = 92.21%

---

6. Create a Huffman tree and assign Huffman codes for the "Star Bright" rhyme used in Section 7A.3. Use <ws> for whitespace instead of underscores.

Ans.

One tree and its corresponding code:



Char-acter	Code	Char-acter	Code
<ws>	01	E	11111
T	100	Y	101000
H	001	N	101010
I	110	O	101011
S	1110	M	101101
G	0000	V	1010010
R	0001	L	1010011
W	10111	B	1011000
A	11110	F	1011001

---

7. Complete the LZ77 data compression illustrated in section 7A.3.

Ans.

0, 0, S   0, 0, T   0, 0, A   0, 0, R   0, 0, _
0, 0, L   0, 0, I   0, 0, G   0, 0, H   1, 1, A
0, 5, B   3, 1, I   7, 4, F   6, 1, R   0, 2, _
0, 5, I   7, 2, E 31, 1, _   1, 1, O   0, 0, N
0, 0, N   5, 1, F   5, 1, S 24, 1, _ 11, 2, M
5, 1, Y 19, 11,I   4, 4, G   0, 0, E   0, 2, T
4, 1, E   9, 8, W   4, 4, T   0, 0, O   0, 0, N
4, 4, <EOF>

---

8. JPEG is a poor choice for compressing line drawings, such as the one shown in Figure 7A.4. Why do you think this is the case? What other compression methods would you suggest? Give justification for your choice(s).

Ans.

The DC Coefficient gives a weighted average of the chrominance and luminance for the other 63 pixels in the block. When we “average” the pixels of a line drawing, we wind up with blocks of gray (or some other shade) instead of the sharp lines in the original graphic. Just about any other compression method would be better. LZ77 and run-length coding would be the fastest and would offer excellent compression because of the “local redundancy” (long runs of a single color) in a line drawing.

---

9. a) The LZ77 compression algorithm falls into which class of data compression algorithms?
   b) Name an advantage of Huffman coding over LZ77.
   c) Name an advantage of LZ77 over Huffman coding.
   d) Which is better?

Ans.

a) Dictionary system
b) Huffman coding will usually result in better compression than LZ77 because it doesn’t matter where in the message the characters are located.
c) LZ77 is faster and can be done in hardware.
d) It depends on what kinds of data you are dealing with and how you define “better.” If “better” means “faster,” LZ77 wins. If “better” means higher compression factor, Huffman will usually win.

---

10. State one feature of PNG that you could use to convince someone that PNG is a better algorithm than GIF.

Ans.

The advantages of PNG over GIF include:

- User-selectable compression modes: "Faster" or "better" on a scale of 0 to 3, respectively;
- Improved compression ratios over GIF, typically 5% to 25% better;
- Error detection provided by a 32-bit CRC (ISO 3309/ITU-142);
- Faster initial presentation in progressive display mode; and, of course,
- PNG is an open international standard, freely available and sanctioned by the World Wide Web Consortium (W3C) as well as many other organizations and businesses.]
