SOLUTIONS TO CHAPTER 2 PROBLEMS

1. The data path cycle is 20 nsec. The maximum number of data path cycles/sec is thus 50 million. The best the machine could do is thus 50 MIPS.

2. The program counter must be incremented to point to the next instruction. If this step were omitted, the computer would execute the initial instruction forever.

3. You cannot say anything for sure. If computer 1 has a five-stage pipeline, it can issue up to 500 million instructions/second. If computer 2 is not pipelined, it cannot do any better than 200 million instructions/sec. Thus without more information, you cannot say which is faster.

4. On-chip memory does not affect the first three principles. Having only LOADs and STOREs touch memory is no longer required. There is no particular reason not to have a memory-to-memory architecture if memory references are as fast as register references. Likewise, the need for many registers becomes less in this environment.

5. The monastery resembles Fig. 2-7, with one master and many slaves.

6. The access time for registers is a few nanoseconds. For optical disk it is a few hundred milliseconds. The ratio here is about 10^8.

7. Sixty-four 6-bit numbers exist, so 4 trits are needed. In general, the number of trits, k, needed to hold n bits is the smallest value of k such that $3^k \geq 2^n$.

8. A pixel requires 6 + 6 + 6 = 18 bits, so a single visual frame is 1.8×10^7 bits. With 10 frames a second, the gross data rate is 180 Mbps. Unfortunately, the brain's processing rate is many orders of magnitude less than this. As an experiment, try watching the random noise on a color television for a few minutes when no station is broadcasting and see if you can memorize the color bit pattern in the noise.

9. With 44,000 samples per second of 16 bits each, we have a data rate of 704 kbps.

10. There are 2 bits per nucleotide, so the information capacity of the human genome is about 6 gigabits. Dividing this number by 30,000, we get about 200,000 bits per gene. Just think of a gene as a 25-KB ROM. This estimate is an upper bound, because many of the nucleotides are used for purposes other than coding genes.

11. For efficiency with binary computers, it is best to have the number of cells be a power of 2. Since 1,073,741,824 is 2^{30}, it is reasonable, whereas 1,000,000,000 is not.

12. From 0 to 9 the codes are: 0000000, 1101001, 0101010, 1000011, 1001100, 0100101, 1100110, 0001111, 1110000, and 0011001.

13. Just add a parity bit: 00000, 00011, 00101, 00110, 01001, 01010, 01100, 01111, 10001, and 10010.

14. If the total length is $2^n - 1$ bits, there are n check bits. Consequently, the percentage of wasted bits is $n/(2^n - 1) \times 100\%$. Numerically for n from 3 to 10 we get: 42.9%, 26.7%, 16.1%, 9.5%, 5.5%, 3.1%, 1.8%, and 1.0%.

15. Each 8-bit character is put into a 12-bit codeword where positions 1, 2, 4, and 8 are check positions. After calculating the check digits and grouping each consecutive 4 bits into a hex digit, the 5 character ASCII string is encoded in hex as: C85 DD1 DF2 5F4 4D8.

16. Each 8-bit ASCII character is encoded into three hex digits. The first set of hex digits: 0D3, has an error in bit 12 (as indicated by the fact that bit 4 and bit 8 have the wrong parity). The next set, DD3 has bit 11 wrong; the set 0F2 has bit 7 wrong; the set 5C1 has bit 9 wrong; the set 1C5 has bit 1 wrong; the last set CE3 does not contain any errors. After the bit positions are corrected and the data extracted from the code words and looked up in the ASCII table, the encoded characters are: babies.

17. With 4096 bits/sector and 1024 sectors/track, each track holds 4,194,304 bits. At 7200 RPM, each rotation takes 1/120 sec. In 1 sec it can read 120 tracks for a rate of 503,316,480 bits/sec or 62,914,560 bytes/sec.

18. At 160 Mbytes/sec and 4 bytes/word, the disk transfer rate is 40 million words/sec. Of the 200 million bus cycles/sec, the disk takes 1/5 of them. Thus the CPU will be slowed down by 20 percent.

19. Logically it does not matter, but the performance is better if you allocate from the outside in. One rotation of the outermost track takes as long as one rotation of the innermost track (because hard disks rotate with constant angular velocity), but there are more sectors on the outermost track, so the transfer rate is higher. It is smarter to use the high-performance sectors first. Maybe the disk will never fill up and you will never have to use the lowest-performance sectors.

20. A cylinder can be read in four rotations. During the fifth rotation, a seek is done to the next cylinder. Because the track-to-track seek time is less than the rotation time, the program must wait until sector zero comes around again. Therefore, it takes five full rotations to read a cylinder and be positioned to start reading the next one. Reading the first 9999 cylinders thus takes 49,995 rotations. Reading the last cylinder requires four rotations, because no final seek is needed. The 49,999 rotations at 10 msec/rotation take 499.99 sec. If the sectors are skewed, however, it may be possible to avoid the fifth rotation per track.

21. RAID level 2 can recover not only from crashed drives but also from undetected transient errors. If one drive delivers a single bad bit, RAID level 2 will correct this, but RAID level 3 will not.

22. In mode 2, the data streams at 175,200 bytes/sec. In a 80-min time span, the number of seconds is 5920, so the size of a 80-min mode-2 CD-ROM is 840,960,000 bytes or 802 MB. Of course, in mode 2 there is no error correction, which is fine for music but not for data. In mode 1, only 2048/2336 of the bits are available for data, reducing the payload to 737,280,000 bytes or 703 MB.

23. The mode does not matter, since the laser has to pulse for preamble bits, data bits, ECC bits, and all the overhead bits as well. The gross data rate at 1x is 75 sectors/sec, each sector consisting of $98 \times 588 = 57,624$ bits. Thus 4,321,800 bits/sec fly by the head at 1x. At 10x, this is 43,218,000 bits/sec. Thus each pulse must last no more than 23.14 nsec (actually slightly less, since there is a blank interval between pulses).

24. Each frame contains 345,600 pixels or 1,036,800 bytes of information. At 30 fps, the rate per second is 31,104,000 bytes/sec. In 133 minutes this amounts to 2.482×10^{11} bytes. The disk capacity is 3.5×2^{30} which is about 3.758×10^{9} bytes. We are off by a factor of 66, so the compression has to be 66x.

25. The read time is the size divided by the speed: $25 \times 2^{30}/4.5 \times 10^{6}$ or about 5965 sec. This is almost an hour and 39 minutes.

26. The usual way to handle this would be to have a bank of 256 24-bit mapping registers in the hardware. Whenever a byte was fetched from the video RAM, the 8-bit number would be used as an index into the mapping registers. The register selected would deliver the 24 bits to drive the display (typically 8 bits each for the red, green, and blue electron guns). Thus indeed 2^{24} colors are available, but at any instant, only 256 are available. Changing colors means reloading the mapping registers.

27. For 32 intensities, we need 5 bits (since $2^5 = 32$). For each pixel we need $5 \times 5 = 25$ bits. This gives 25×10^8 bits/frame. A temporal resolution of 10 msec means 100 frames/sec so the bit rate is 2500×10^8 bps. This is the same as 312.5×10^8 bytes/sec. Using 1 GB = 10^9 bytes, this is 312.5 GB/sec.

28. The display must paint $1920 \times 1080 \times 75$ pixels/sec. This is a total of 155.52 megapixels. Thus the pixel time is 6.43 nsec.

29. A page has 4000 characters. Each character uses 25% of 4 mm^2, or 1 mm^2. Thus a page has 4000 mm^2 of toner. With a thickness of 25 microns (0.025 mm), the volume of toner on a page is 100 mm^3. The capacity of the toner cartridge is 400 cm^3 or 400,000 mm^3. A cartridge is good for 4000 pages.

30. Each interval can transmit 6 bits, so the data rate is $6n$ bps.

31. A 12-MHz cable with QAM-64 has a data rate of 72 Mbps. With nf computers sharing the bandwidth, each user gets $72/nf$ Mbps. Thus the cable user gets better service if $72/nf > 2$. An alternative way to write this is $nf < 36$. In other words, if the 72-Mbps bandwidth is being shared by 36 active users, it is the same as 2-Mbps ADSL; with fewer users, cable wins; with more users, ADSL wins.

32. Each uncompressed image file is 18 million bytes. After 5x compression, it is 3.6 million bytes. To write this in 2 sec requires a data rate of 1.8 MB/sec.

33. The uncompressed image is 144 million bytes. The compressed image is 28.8 million bytes. The number of images stored is thus $8 \times 2^{30}/28.8$ million or 298 images.

34. A typical computer-science textbook has about a million characters, so it needs about 1 MB. Ten thousand books require 10^{10} bytes. A CD-ROM holds 700 MB, so you need 15 CD-ROMs. A dual-layer, single-sided DVD holds 4.7 GB, so the whole library fits on three DVDs.