CS330 Architecture and Organization
Assignment Chapter 1

Solution key

Problem 1.1 — (2 points) Aside from the smart cell phones used by a billion people, list and describe four other types of computers. (Section 1)

Answer:

1. supercomputers
2. servers
3. personal computers
4. microcontrollers

Problem 1.3 — (3 points) Describe the steps that transform a program written in a high-level language such as C into a representation that is directly executed by a computer processor. (Section 3)

Answer:

1. The first step may be to run a pre-processor that expands macros, though not all languages use a pre-processor.
2. Then the source code, such as C code, is translated into assembly code. (Some languages may skip this step and convert program source code directly to object code.)
3. The assembly code is assembled into object code, which is the first stage at which machine executable representations start to appear.
4. The object code is linked with library code, and this step finalizes the destination of all branch instructions. When complete, the resulting binary can be directly executed by a computer processor.

Problem 1.4 — Assume a color display using 8 bits for each of the primary colors (red, green, blue) per pixel and a frame size of 1280×1024. (Section 4)

a. (2 points) What is the minimum size in bytes of the frame buffer to store a frame?

Answer: Since a single pixel is formed from three 8-bit color values, each pixel requires at least 3 bytes of storage. Since the frame size is 1280 pixels, the minimum number of bytes required would be:

$$1280 \times 1024 \times 3 = 3932160 \text{ bytes}$$

b. (2 points) How long would it take, at a minimum, for the frame to be sent over a 100 Mbits/s network?

Answer: We must send $3932160 \times 8 = 31457280$ bits, and unit arithmetic tells us we must divide by the speed of the link to get:

$$(31{,}457{,}280 \text{ bits}) \div (100{,}000{,}000 \text{ bits/s}) = 0.3145728 \text{ s}$$

Problem A — Consider three different processors that implement the same instruction set architecture. Call the implementations P_1, P_2, and P_3:

Processor	Clock Rate	CPI
P_1	3 GHz	1.5
P_2	2.5 GHz	1.0
P_3	4.0 GHz	2.2

(Section 6)

a. (4 points) Calculate the clock tick time for each processor. Give your answer in picoseconds, rounded to the closest picosecond.

Answer: The unit giga represents 10^9, pico represents 10^{-12}, and Hz is the reciprocal of seconds, so we use reciprocals and then convert units.

- $P_1 : \dfrac{1}{3 \times 10^9 \text{ 1/s}} = 3.33333 \times 10^{-10} \text{ s} \cdot \dfrac{10^{12} \text{ picosecond}}{\text{s}} = 333.33 \text{ picoseconds}$
- $P_2 : \dfrac{1}{2.5 \times 10^9 \text{ 1/s}} = 4.0 \times 10^{-10} \text{ s} \cdot \dfrac{10^{12} \text{ picosecond}}{\text{s}} = 400 \text{ picoseconds}$
- $P_3 : \dfrac{1}{4.0 \times 10^9 \text{ 1/s}} = 2.5 \times 10^{-10} \text{ s} \cdot \dfrac{10^{12} \text{ picosecond}}{\text{s}} = 250 \text{ picoseconds}$

All of these can be verified using the "units" utility installed on sand.truman.edu.

```
$ units -v
You have: 1 / (3 GHz)
You want: picoseconds
        1 / (3 GHz) = 333.33333 picoseconds
        1 / (3 GHz) = (1 / 0.003) picoseconds
```

b. (2 points) Which processor has the highest performance, if we are interested only in clock cycles per second?

Answer: Obviously P_3 is the fastest, if we only care about clock cycles.

c. (3 points) Suppose each processor executes a program for 10 seconds. Calculate the number of clock cycles used. Give your answer rounded to the closest whole number.

Answer:

- $P_1 : (3.0 \times 10^9 \text{ clocks/s}) \cdot (10 \text{ s}) = 3.0 \times 10^{10} \text{ clocks} = 30{,}000{,}000{,}000 \text{ clocks}$
- $P_2 : (2.5 \times 10^9 \text{ clocks/s}) \cdot (10 \text{ s}) = 2.5 \times 10^{10} \text{ clocks} = 25{,}000{,}000{,}000 \text{ clocks}$
- $P_3 : (4.0 \times 10^9 \text{ clocks/s}) \cdot (10 \text{ s}) = 4.0 \times 10^{10} \text{ clocks} = 40{,}000{,}000{,}000 \text{ clocks}$

d. (3 points) Calculate the average number of instructions executed per second for each processor. Which processor has the highest performance, if we are interested only in the average number of instructions executed per second?

Answer:

- $P_1 : (3{,}000{,}000{,}000 \text{ clocks/s}) \div (1.5 \text{ CPI}) = 2{,}000{,}000{,}000 \text{ instructions/s}$

- P_2 : (2,500,000,000 clocks) ÷ (1.0 CPI) = 2,500,000,000 instructions/s
- P_3 : (40,000,000,000 clocks) ÷ (2.2 CPI) = 1,818,181,818 instructions/s

If we only care about the number of instructions executed, then P_2 is the fastest processor.

e. (3 points) If the processors each execute a particular program in 10 seconds, find the number of instructions used by each processor.

Answer: Using the ten second clock counts from part c. and dividing by CPI (or multiplying our answers from part d. by ten seconds), we have:

- P_1 : (30,000,000,000 clocks) ÷ (1.5 CPI) = 20,000,000,000 instructions
- P_2 : (25,000,000,000 clocks) ÷ (1.0 CPI) = 25,000,000,000 instructions
- P_3 : (40,000,000,000 clocks) ÷ (2.2 CPI) = 18,181,818,182 instructions

Problem B — Consider two different implementations of an instruction set architecture: P_1 and P_2. The instructions in this ISA can be divided into four different categories: A, B, C, and D. The following table gives the clock rate of each processor, along with the CPIs of the instructions from each class.

	P_1	P_2
Clock Rate	2.5 GHz	3 GHz
CPI for class A instructions	1	2
CPI for class B instructions	2	2
CPI for class C instructions	3	2
CPI for class D instructions	4	2

(Section 6)

When we use the llvm compiler to compile the source code for a particular program, the compiler uses $2.5 \cdot 10^8$ instructions, drawn from the four classes as follows: 10% from A, 20% from B, 50% from C, and 20% from D.

a. (4 points) Calculate the average CPI used during the compilation for both processors?

Answer: For each processor, the answer is a weighted sum of the four classes.

For P_1 the weighted average is:

$$0.10 \cdot 1 + 0.20 \cdot 2 + 0.50 \cdot 3 + 0.20 \cdot 4 = 2.8 \text{ CPI}$$

For P_2 the calculation is trivial: 2 CPI.

b. (4 points) How many clock cycles does the compilation take on each processor?

Answer: According to the setup of the question, compilation requires 2.5×10^8 instructions, and we multiply by the CPI.

- P_1 : $(2.5 \times 10^8$ instructions$) \cdot (2.8$ clocks/instruction$) = 700{,}000{,}000$ clocks
- P_2 : $(2.5 \times 10^8$ instructions$) \cdot (2.0$ clocks/instruction$) = 500{,}000{,}000$ clocks

c. (4 points) How much time does the compilation take on each processor?

Answer:

- P_1 : (700,000,000 clocks) $\div$ (2.5×10^9 clocks/s) = 0.28 s
- P_2 : (500,000,000 clocks) $\div$ (3.0×10^9 clocks/s) = 0.17 s

d. (2 points) Which processor is faster on this task?

Answer: Processor P_2 is faster because it finishes in less time.

e. (4 points) Calculate the performance of each processor in terms of compilations per second.

Answer:

- P_1 : (1 compilation)/(0.28 s) = 3.57 compilation/s
- P_2 : (1 compilation)/(0.17 s) = 6.00 compilation/s

f. (4 points) Use your answer from e. to determine which processor has the better performance, and then calculate how much faster that processor is than the slower processor.

Answer: P_2 performs faster, and it is $6/3.57 = 1.68$ times as fast as P_1.