1.3 [2] <§1.3> 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.

A high-level program is entered into a compiler which, as its name states, compiles it into an assembly language statement. Then it is passed into an assembler, which then translates the statement into binary instructions.

1.4 [2] <§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.

a. What is the minimum size in bytes of the frame buffer to store a frame?

For this case: frame size = 1280×1024, colordepth = 8 bits per primary color, so this would be (8 bits × 3 colors) = 24 bits. We know we must convert to bytes, and 1 byte = 8 bits so,

$$\text{color depth} = 24\,\cancel{\text{bits}} \times \frac{1\text{ bytes}}{8\,\cancel{\text{bits}}} = \frac{24}{8}\text{ bytes} = 3\text{ bytes}$$

the formula is minimum size (bytes) = frame size × color depth

$$\boxed{\text{minimum size (bytes)} = (1280 \times 1024) \times 3\text{ bytes} = 3{,}932{,}160}$$

b. How long would it take, at a minimum, for the frame to be sent over a 100 Mbit/s network?

Convert bytes to bits, then to Mbit

$$\text{Min size} = 3{,}932{,}160\text{ bytes} \times \frac{8\text{ bits}}{1\text{ byte}} = 31{,}457{,}280\text{ bits}$$

1 Megabits = 1×10^6 bits

100 Megabits = 1×10^8 bits

$$\text{Minimum Transmission time} = \frac{\text{min size (bits)}}{\text{speed (bits/s)}} = \frac{31{,}457{,}280\,\cancel{\text{bits}}}{1 \times 10^8\,\frac{\cancel{\text{bits}}}{s}}$$

$$= 0.3145728$$

$$\boxed{\text{Minimum Transmission time} = 0.3145728\text{ sec}}$$

1.5 [4] <§1.6> Consider three different processors P1, P2, and P3 executing the same instruction set. P1 has a 3 GHz clock rate and a CPI of 1.5. P2 has a 2.5 GHz clock rate and a CPI of 1.0. P3 has a 4.0 GHz clock rate and has a CPI of 2.2.

a. Which processor has the highest performance expressed in instructions per second?

$$CPI = \frac{\text{CPU clock rate}}{\text{Instruction count}} \rightarrow \text{Instruction Count} = \frac{\text{CPU clock cycles}}{CPI}$$

$$P1 = \frac{(3\times10^9)}{1.5} = 2\times10^9 \, \frac{ins}{sec} \qquad P2 = \frac{(2.5\times10^9)}{1.0} = 2.5\times10^9 \, \frac{ins}{sec}$$

$$P3 = \frac{(4\times10^9)}{2.2} = 1.8\times10^9 \, \frac{ins}{sec}$$

$\boxed{\therefore \text{P2 has the highest performance}}$

b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions.

CPU clock cycles = clock rate * execution time

\# of instructions = instruction rate * execution time

answers from part a

$P1 = (3\times10^9) * 10 = 3\times10^{10}$ $\quad$ $P2 = (2.5\times10^9) * 10 = 2.5\times10^{10}$

$P1 = (2\times10^9) * 10 = 2\times10^{10}$ $\quad$ $P2 = (2.5\times10^9) * 10 = 2.5\times10^{10}$

$P3 = (4\times10^9) * 10 = 4\times10^{10}$

$P3 = (1.8\times10^9) * 10 = 1.8\times10^{10}$

c. We are trying to reduce the execution time by 30% but this leads to an increase of 20% in the CPI. What clock rate should we have to get this time reduction?

execution time = 10 $\quad$ reduced by 30% (3) = 7

20% = 0.3 $\quad$ P1 CPI = 1.5 = 1.8

20% = 0.2 $\quad$ P2 CPI = 1.0 = 1.2

20% = 0.44 $\quad$ P3 CPI = 2.2 = 2.64

$$\text{CPU time} = \frac{\text{\# of instructions} \times CPI}{\text{clock rate}}$$

$$\text{clock rate} = \frac{\text{\# of instructions} \times CPI}{\text{CPU time}}$$

$$P1 = \frac{(2\times10^{10})\times1.8}{7} = 5.14\times10^9 = 5.14\text{ GHz}$$

$$P3 = \frac{(1.8\times10^{10})\times2.64}{7} = 6.79\times10^9 = 6.79\text{ GHz}$$

$$P2 = \frac{(2.5\times10^{10})\times1.2}{7} = 4.29\times10^9 = 4.29\text{ GHz}$$

1.6 [20] <§1.6> Consider two different implementations of the same instruction set architecture. The instructions can be divided into four classes according to their CPI (class A, B, C, and D). P1 with a clock rate of 2.5 GHz and CPIs of 1, 2, 3, and 3, and P2 with a clock rate of 3 GHz and CPIs of 2, 2, 2, and 2.

Given a program with a dynamic instruction count of 1.0E6 instructions divided into classes as follows: 10% class A, 20% class B, 50% class C, and 20% class D, which implementation is faster?

Processor	A	B	C	D
P1	1	2	3	3
P2	2	2	2	2

$$\text{Execution time} = \frac{\text{Clock Cycle } P_I}{\text{Clock Rate}}$$

$$\text{Execution time P1} = \frac{6.5 \times 10^9}{2.5 \times 10^9} = 2.6 \qquad \text{Execution time P2} = \frac{9 \times 10^9}{3 \times 10^9} = 3$$

a. What is the global CPI for each implementation?

$$\text{Global CPI} = \sum_{i=1}^{n} (CPI_i \times C_i)$$

$$CPI_{P1} = (1\times0.1)+(2\times0.2)+(3\times0.5)+(3\times0.2) = 0.1+0.4+1.5+0.6 = 2.6 \text{ cycles}$$

$$CPI_2 = (2\times0.1)+(2\times0.2)+(2\times0.5)+(2\times0.2) = 0.2+0.4+1.0+0.4 = 2 \text{ cycles}$$

$$\boxed{\therefore \text{P1 is faster at 2.6 cycles}}$$

b. Find the clock cycles required in both cases.

Clock cycle P1 = Clock rate * CPI

$$\therefore P1 = (2.5\times10^9) * 2.6 = 6.5\times10^9$$

$$\therefore P2 = (3\times10^9) * 3 = 9\times10^9$$

1.7 [15] <§1.6> Compilers can have a profound impact on the performance of an application. Assume that for a program, compiler A results in a dynamic instruction count of 1.0E9 and has an execution time of 1.1 s, while compiler B results in a dynamic instruction count of 1.2E9 and an execution time of 1.5 s.

a. Find the average CPI for each program given that the processor has a clock cycle time of 1 ns.

Compiler A: instruction count $= 1.0 \times 10^9$

execution time $= 1.1$ sec

Compiler B: instruction count $= 1.2 \times 10^9$

execution time $= 1.5$ sec

clock rate $= \dfrac{1}{\text{clock cycle time}}$ $\therefore$ clock rate $= 1.0 \times 10^9$

clock cycle $= 1\text{ ns} = 1.0 \times 10^{-9}$

$$\text{CPU time} = \frac{\text{instruction count} \times \text{CPI}}{\text{Clock rate}} \longrightarrow \text{CPI} = \frac{\text{CPU time} \times \text{Clock rate}}{\text{Instruction Count}}$$

$$\boxed{\begin{aligned} \text{CPI}_A &= \frac{1.1 \times 1.0 \cancel{\times 10^9}}{1.0 \cancel{\times 10^9}} = \frac{1.1 \times 1.0}{1.0} = 1.1 \\ \text{CPI}_B &= \frac{1.5 \times 1.0 \cancel{\times 10^9}}{1.2 \cancel{\times 10^9}} = \frac{1.5 \times 1.0}{1.2} = 1.3 \end{aligned}}$$

b. Assume the compiled programs run on two different processors. If the execution times on the two processors are the same, how much faster is the clock of the processor running compiler A's code versus the clock of the processor running compiler B's code?

$$\frac{\text{CPU Performance A}}{\text{CPU Performance B}} = \frac{\text{Execution time B}}{\text{Execution time A}} = \frac{1.5}{1.1} = 1.4$$

$\boxed{\therefore \text{Clock of processor A is 1.4 times as fast as B's}}$

c. A new compiler is developed that uses only 6.0E8 instructions and has an average CPI of 1.1. What is the speedup of using this new compiler versus using compiler A or B on the original processor?

New Compiler: instruction count $= 6.0 \times 10^8 = 0.6 \times 10^9$

CPI $= 1.1$

$$\frac{\text{Execution Time}_{\text{Old}}}{\text{Execution Time}_{\text{New}}} \qquad \text{A vs New} = \frac{1.1}{0.6} = 1.83 \qquad \text{B vs New} = \frac{1.5}{0.6} = 2.5$$

$\boxed{\therefore \text{The Speed up against compiler A is 1.83 and against compiler B is 2.5}}$