Homework #5

1. Consider the densities of information in the human brain and other devices. The human brain has a mass of 1300 grams and a volume of about 1 liter (10^{-3} m^3). Using these results:

   (a) The human brain might have 10^{11} neurons (some groups say 10^{10}). On average, each of these neurons has 10^4 connections. By multiplying the two, how many "bits" of information are there in the human brain?
   Each connection is a bit. Therefore there are $10^{11} \times 10^4 = 10^{15}$ connections, therefore 10^{15} bits. I will also accept 10^{14} bits.

   (b) Now given the mass of the brain in grams, how many bits per gram are stored in the human brain? Furthermore, given the volume of the brain, how many bits are stored per *cubic centimeter* of the brain?
   There are 1300 grams in the brain. Thus, on average there are:

   $$N_m = \frac{10^{15}}{1300} = 7.7 \times 10^{11} \text{ bits/gram}$$

   I will also accept 7.7×10^{10} bits/gram. Furthermore, 1 liter is 1000 cm^3 (since 10^6 cm^3 = 1 m^3). Then the information content per cubic centimer:

   $$N_V = \frac{10^{15}}{1000} = 10^{13} \text{ bit/cm}^3$$

   I will also accept 10^{12} bits/cm^3.

   (c) A typical Fujitsu™ hard disk (the storage medium of information in a computer) has a mass of 20 grams and a surface area of 6 cm^2 and a total information content of 20 gigabytes, or 160 gigabits (1.6×10^{11} bits). Calculate the information density per gram of hard disk and the information density per square centimeter of the disk. How does the number of bits per gram compare with the human brain (the information density per gram in the brain divided by the information density per gram in the chip)?
   The information content of a Fujitsu per gram:

   $$N_m = \frac{1.6 \times 10^{11}}{20} = 8 \times 10^9 \text{ bits/gram}$$

   The information density per square centimeter then becomes:

   $$N_a = \frac{1.6 \times 10^{11}}{6} = 2.67 \times 10^{10} \text{ bits/cm}^2$$

   The ratio of information density per unit mass of a hard disk to that of the human brain becomes $8 \times 10^9 / (7.7 \times 10^{11}) = 1/96.25$ that of the human brain for the higher end of the brain's information density; it is 1/9.625 for the lower end.

   (d) The power output of a typical Pentium 4 processor (the CPU of a modern computer) is 40 W/cm^2 on a chip that is 1 cm × 1 cm in dimensions. This chip can perform 3×10^9 calculations per second. Based on these two results, how many Joules of energy are required for each calculation?
   The P4 puts out 40 W. The energy per calculation is given by:

   $$E = \frac{40 \text{ J/s}}{3 \times 10^9 \text{ calculations/s}} = 1.33 \times 10^{-8} \text{ J/calculation}$$

(e) The power output of the human brain is 25 Watts. A lower end for the operational capacity of the brain is 10^{13} calculations/second. Given these two results, how many energy is required for the brain to perform one "calculation?" How does this compare to a typical Pentium chip?
The energy per calculation of the human brain is $25/10^{13} = 2.5 \times 10^{-12}$ Joules. This is smaller by a factor of $1.33 \times 10^{-8}/2.5 \times 10^{-12} = 5300$.

2. Given the table used by Sebastian van Hoerner in his 1961 *Science* article, and which is given in the text and notes, put your own results for the average lifetime of a civilization. This is, in my opinion, purely subjective.
This is up to you. I have to check each result individually. Specifically, I will check for $P_i L_i$ calculated correctly, $\sum_i P_i L_i$ calculated correctly, and $\sum_i P_i = 1$.