ECSE 310 Thermodynamics of Computer, Fall 2025

Homework 1: IT energy use and hardware scaling (Problem Analysis)

Assigned: August 28th 2025

Due: September 21st 2025, 11:59 pm

Late policy: 1% deduction per hour

Instructions: Please use the MyCourses tool to submit your answers. If you need to attach a scanned or photographed handwritten page, please check to make sure that it is legible. Illegible pages will be rejected and zero credit will be given.

Academic integrity reminder: In submitting this assignment on MyCourses you are attesting that it is the result of your own work.

Homework is worth 60 points in total. Weights for each sub-question are shown in square brackets.

1. We need to design a liquid-based cooling system for a home computer. Assume that the liquid is distilled water, and that the processor dissipates 120 W when being operated at its maximum rate. Water enters the cooling system at 22 °C and exits at 80°C after absorbing heat from the processor. We will assume that the water remains at constant pressure (i.e.'isobaric conditions') which implies a heat capacity of 4.2 J/g/K over that temperature range. We can also assume that density remains constant. What flow rate (in L/min) is required to dissipate 120 W?

   [10 points]

2. You measure the total resistance of an integrated circuit line to be 125 Ω. You know that the line is 1 mm long and 0.4 µm wide.
   a. What is the resistance/square of the line? [3 points]
   b. The capacitance per unit area is 75 aF/µm^2. What is the Elmore delay for the 1 mm line? [3 points]
   c. At what line length would the maximum permitted signal frequency fall below 10 GHz? [4 points]

   [10 points total]

3. The attached spreadsheet provides data from the Top500 supercomputer performance website (www.top500.org). Use this data, together with suitable tools for curve fitting (Excel, Matlab, Mathematica, Python or any other method of your choice) to answer the questions below. *Please upload the spreadsheet, calculations or code that you used with your answer*.
   a. Assuming **exponential growth** in peak performance (R_{max}) what is the doubling time in years? [3 points]
   b. Calculating the doubling time in peak performance for the **first 10 years** of this series and compare it to the doubling time for the **last 10 years** of this series. What does this imply about our assumption of sustained exponential growth in performance? [2 points]
   c. Assuming **linear growth** in power consumption, by what factor does power use increase each year? [2 points]
   d. Assuming that the peak performance doubling rate of the last 10 years holds into the future (and taking the power growth rate from the entire series) use the parameters that you have obtained to **predict the year** in which we could expect to see a **100 Exaflop** supercomputer and **forecast its power consumption**. [5 points]
   e. If a typical home requires around 10,000 kWh of electricity per year, **how many homes** could be run on the same electricity as this future supercomputer? [3 points]

[15 points]

4. The Power PC 750 'Arthur' microprocessor was released by IBM/Motorola in 1997. It was on the 260 nm node size and had 6.35 million transistors, operating at a clock speed of 366 MHz and with a supply voltage of 2.6V and consumed 7.3W. The die size was 67 mm^2.

a. Use the data presented in Figure 4 of the chapter by Zhirnov to estimate the 'bottom-up' and 'top-down' **switching energy per transistor**. [3 points]

b. Use this data to estimate **capacitance** of a single transistor [3 points]

c. Given the known power consumption and the estimated transistor switching energy, estimate the **activity factor** [3 points]

d. Assuming that Moore's law held for the next 10 years and that all physical dimensions, voltage and current scaled accordingly, while the chip area remained constant, use the Denard scaling laws to estimate **the following device values for 2007**:
   i) Transistor count [2 points]
   ii) Transistor size [2 points]
   iii) Clock speed [2 points]
   iv) Bottom-up switching energy [2 points]
   v) Supply voltage [2 points]
   vi) Total device power consumption [2 points]

e. Now that you have calculated the scaled node size, either using the graph from Zhirnov or some other way, look up the specifications of a microprocessor that had a similar node size and compare the specifications (if the die area is different, then consider the transistors per unit area and power dissipation per unit area). How do these compare with your calculations? Where they differ, why do the Denard scaling laws fail to predict these accurately? [4 points]

[25 points total]