Problem 1 [20 pts]
   a) Consider the following communication interfaces. For each protocol, i) specify if it is a parallel protocol or serial one, and ii) give an example where each protocol is used in today's embedded systems. iii) Explain why the protocol is suitable for the application you choose.

   - **AMBA BUS:**

   - **I2C:**

   - **PCI express:**
Problem 2 [30 pts]
Consider the following list of operations.

\[
\begin{align*}
o_1 &= i_1 + i_2 \\
o_2 &= o_1 \times i_3 \\
o_3 &= o_1 + i_5 \\
o_4 &= o_2 \times o_3 \\
o_5 &= i_6 \times i_7 \\
o_6 &= i_8 + i_9 \\
o_7 &= o_5 + o_6 \\
o_8 &= o_7 + o_4
\end{align*}
\]

The variables starting with “i” are inputs and the ones starting with “o” are the outputs. There are 9 inputs and 8 outputs. The operations are computed by adders and multipliers.
- Multipliers and adders can operate on 2 operands at once.
- An adder consumes 0.4 $W$, while a multiplier consumes 1 $W$.
- Power consumption of any idle unit is 0.1 $W$.
- A multiplier takes 2 cycles, whereas an adder takes 1 cycle to produce the output.
- One cycle takes 1 ns.

Use this notation style (Note that this example does not correspond to the current problem)

Example:
\[
\begin{align*}
o_1 &= i_1 \times i_2 \\
o_2 &= i_3 \times i_4
\end{align*}
\]
a) Give the **ASAP** schedule assuming no resource constraints, (i.e., you can use as many adders and multipliers as you need at a time.)

b) Give the **ALAP** schedule assuming no resource constraints
c) Give the list schedule assuming that you have only 1 adder and 1 multiplier. Use the mobility metric (obtained from ASAP and ALAP) for the priority. If multiple units have the same priority, use numerical order of the outputs to break the tie (e.g., if two units computing o1 and o2 have the same priority, run task o1 first).

a) Answer the following questions:
- What is the total energy consumption according to the LIST schedule you found in part c)?
  \text{Total energy (}n\text{J}) =

- What is the minimum power consumption?
  \text{Minimum power (}W\text{)} =
**Problem 3 [20 pt]**

You are given five tasks (T1 – T5) and one each of five different hardware implementations: HW1, HW2, HW3, HW4, and a general-purpose processor P (each costing $10, $15, $5, $25, and $30 respectively). The table below shows the number of seconds it takes to run each task on of the possible hardware implementations. Each hardware element can only run one task at a time, but different hardware elements may work in parallel. The task graph has a deadline of 60 seconds.

<table>
<thead>
<tr>
<th></th>
<th>HW1</th>
<th>HW2</th>
<th>HW3</th>
<th>HW4</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>15</td>
<td>-</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>25</td>
</tr>
</tbody>
</table>

For each of the following schedules, provide a feasible partitioning of tasks among hardware elements, the total system cost, and the total execution time of all tasks for the task graph.

(For example, you may partition like “T1:HW1, T2:HW2, T3:HW4, T4:HW4, T5:HW2”. But, you cannot assign “T1:HW1, T2:HW2, T3:HW2, T5:HW3, T5:P”, since this needs two HW2s to run T2 and T3 at the same time.)

a) Minimum execution time schedule.

b) Minimum cost schedule. Note that the minimum cost schedule may miss the deadline.

c) The cheapest schedule that meets the deadline of the graph.
Problem 4 [30 pts]
Consider the following Petri Net N specification with P places, T transitions, A flows and W arc weights:
\[ P = \{P_1, P_2, P_3, P_4, P_5, P_6\} \]
\[ T = \{t_1, t_2, t_3, t_4, t_5, t_6\} \]
\[ A = \{(P_1, t_1), (P_1, t_3), (P_1, t_4), (P_2, t_2), (P_3, t_2), (P_4, t_4), (P_4, t_5), (P_6, t_6), \\
(t_1, P_2), (t_1, P_3), (t_2, P_1), (t_3, P_4), (t_4, P_5), (t_5, P_6), (t_6, P_6)\} \]
\[ W(P_1, t_3) = 2, W(P_6, t_6) = 2, W(t_5, P_6) = 2, W(t_6, P_6) = 2 \]
\[ \text{... all other arc weights are 1.} \]

Given initial marking \( M_0 = [1, 1, 0, 0, 0, 0] \) for \( \{P_1, P_2, P_3, P_4, P_5, P_6\} \):

a) Draw the Petri Net
b) Draw the reachability graph

c) Answer the following questions in one line:
- What is the liveness of transition t1?
- What is the liveness of transition t3?
- What is the liveness of transition t4?
- Is the net pure?
- Is the net conservative?