a) Name three different types of hazards that can be encountered in pipelined architectures.

b) Given a generic 5-stage pipeline, indicate which one(s) of the instructions in the following sequence will generate a hazard and what type of hazard? Justify your answer. Assume the processor does not have a branch predictor and branch conditions are computed in the ALU.

```
ADD    R1, R2, R3 ; R1 ← R2 + R3
SUB    R5, R1, R3 ; R5 ← R1 - R3
BEQ    R5, R4, 100 ; Branch to PC+100 if R4 = R5
ADD    R1, R3, R5 ; R1 ← R3 + R5
ADD    R1, R2, R4 ; R1 ← R2 + R4
```

c) If the sequence of instructions above produces a hazard, is it possible to avoid it by operand forwarding? Justify your answer using specific instructions from part b).
The instruction type breakdown of a program is given in the table below.

<table>
<thead>
<tr>
<th>Number of instructions</th>
<th>ALU</th>
<th>Load</th>
<th>Store</th>
<th>Branch</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>900</td>
<td>500</td>
<td>300</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Compute the execution time of this program on two separate processors with given CPI's for each type of instruction as shown in the table below. Assume Processor 1 runs at 1GHz whereas Processor 2 runs at 1.6GHz.

<table>
<thead>
<tr>
<th></th>
<th>ALU</th>
<th>Load</th>
<th>Store</th>
<th>Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor 1</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>3.5</td>
</tr>
<tr>
<td>Processor 2</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>
Calculate the branch prediction accuracy (= number of correct predictions / number of total predictions) of the following branch outcome sequence using the 2-bit predictor shown below. Assume that the initial state is one on bottom-left.

Branch outcome sequence (T means “branch-taken” and N means “branch-not-taken”):
T, T, N, N, T, N, T, N, T
Given the bit pattern 1011 0011, what does it represent in decimal, assuming that it is:

a. a **signed** (two's complement) integer.

b. an **unsigned** integer.
Consider a Boolean function $f(A, B, C, D)$

a) What is the maximum number of product terms $f$ can have in its minimal SOP expression? Give an example of such function $f$.

b) Is it possible for $f$ to have three product terms in its minimal SOP expression and three sum terms in its minimal POS expression? If yes, give an example. If no, explain why.
Simplify the following Boolean expression: 
\[ f(A, B, C, D) = A'C'D + A'BD + BCD + ABC + ACD' \]
Given the function below, answer the following questions.

\[ F = \sum m(0,2,5,7,8,10,13,15) + dc(1,3) \]

a) Write the **canonical** SOP for \( F \).

b) Write the **minimal** SOP for \( F \).

c) Draw the circuit for \( F \) using any combination of gates.
Simplify the following equations using theorems and axioms of Boolean algebra. DO NOT USE K-MAPS!

a) \[ F(A, B, C, D) = (\overline{a}b + a)\overline{a} + (c + d)(c + \overline{d}) \]

b) \[ G(A, B, C) = \overline{b}c + bc + a\overline{b}c + abc \]

c) \[ H(A, B, C) = \overline{a}B + \overline{a}b\overline{c} + (a + \overline{c}) \]
Problem: CM9  
Area: Embedded Computer Systems  
Code #________

a) (30 %) List at least 5 important factors/criteria when choosing a microcontroller and explain your choices.

b) (30 %) What is the purpose for having many types of addressing modes? Enumerate at least 4 different addressing modes generally used in microcontrollers.

c) (30 %) Give a definition for interrupts and explain what purpose and advantage they serve in a digital system.

d) (10 %) List 2 differences between general-purpose microprocessors and microcontrollers and explain your choices.
Assume you are given an 8051 microcontroller with a clock running at 12MHz. This microcontroller has a timer that can run in two modes. In the first mode, the microcontroller uses a 16-bit number as input and the initial value needs manual reload on an overflow. In the second mode, it uses an 8-bit value which auto-reloads on overflow. One timer tick is equivalent to 12 oscillator/clock ticks. Assume the 16-bit number can be written as TH0 and TL0 for the high and low byte, respectively, and the 8-bit number only needs to be loaded with the TH0 value for operation. A delay can be generated by starting your time with a particular value and have it count up to its "overflow" value. Your task is to find the timer initialization value to create a 2μs delay and explain which timer mode you would use and why. Show your work clearly for full credit.
a) (50%) Write a C-language code that executes the same operation as the following 8051 assemble code. Assume assembly syntax to be: "<instruction> <destination>, <source>. Make sure to declare any needed variables.

```c
funny_name segment data
  w: DS2; byte variable declaration
  z: DS 1; another variable declaration
CSEG AT 0000H
  MOV w, #3333h
  MOV A, #32d
  CLR C
  RLC A
  MOV R0, #0Ah
LOOP:  ADD A, R0
        DJNZ R0, LOOP
        MOV z, A
        END
```

b) (50%) You can write a code in C-language (high level) or in assembly. Give at least two advantages (pros) of using each.
Write an assembly program to find the bit position of the first '1' (starting from the most significant bit) in an 8-bit number stored in register R7. You can consider either 8015 or other embedded processor. Assume you have Rotate Right (RR) and Rotate Left (RL) instructions, but no Shift Left or Shift Right instructions. Also, the microcontroller uses Carry bit to save overflow bit (while pushing the previous Carry bit back into the register). Your program should output the bit position of the first '1' on Port 2 (P2). Assume it is possible the given 8-bit number can have no '1's.
Describe the pros and cons of the LMS algorithm in detail. Give some math for the learning step at one weight and explain where each term comes from.
Answer both questions below.

1. Complete the table below, which represents the seven-layer hybrid OSI network model. For each layer, state the name, a one-sentence description of the functionality, and one protocol that is used in implementing the services of the layer.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name</th>
<th>Functionality</th>
<th>Sample Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. In the table above, which can represents a layered network model, exactly one protocol data unit (PDU) in layer \( N \) is encapsulated in a PDU at layer \( (N-1) \). It is also possible to break one \( N \)-level PDU into multiple \( (N-1) \)-level PDUs (segmentation) or to group multiple \( N \)-level PDUs into one \( (N-1) \)-level PDU (blocking).

   a. In the case of segmentation, is it necessary that each \( (N-1) \)-level segment contain a copy of the \( N \)-level header? Why or why not?

   b. In the case of blocking, is it necessary that each \( N \)-level PDU retain its own header, or can the data be consolidated into a single \( N \)-level PDU with a single \( N \)-level header? Why or why not?
Problem: CM18

Area: Networking

Code #__________

Answer all four questions below. Show your work for every answer.

1. Compare the two basic flow control mechanisms: stop-and-wait and sliding window. Describe the advantages and disadvantages of each scheme.

2. Consider a satellite link with data rate of 1Mbps and total link delay of 0.5s. User data is sent as fast as possible, using 2500 byte (octet) packets. What is the effective throughput achievable by the (i) stop-and-wait scheme and (ii) the sliding window scheme with a window size of 20? For the scenario from (2), calculate the optimal window size, i.e., the window size that will maximize throughput. What will be the effective throughput in such a case?
Answer both questions below. Show every step of your work.

1. Hosts A and B are each connected to a switch S via 100-Mbps links as in the figure below. The propagation delay on each link is 20 μs. S is a store-and-forward device; it begins retransmitting a received packet 35 μs after it has finished receiving it. Calculate the total time required to transmit 10,000 bits from A to B
   a. As a single packet
   b. As two 5000-bit packets sent one right after the other

[Diagram of A, S, B]

What is the Hamming distance of two-dimensional parity? Justify your answer.
Answer both questions below.

1. Provide each of the following parameters for each of the network classes A, B, and C, respectively. Be sure to consider any special or reserved addresses in your calculations.
   a. Number of bits in network portion of address
   b. Number of bits in host portion of address
   c. Number of distinct networks allowed
   d. Number of distinct hosts allowed per network
   e. Integer range of first (most significant) byte of IP address

2. An organization has been assigned the prefix 212.1.1//24 (class C) and wants to form subnets for four departments, with hosts as follows:

   A    75 hosts
   B    35 hosts
   C    20 hosts
   D    18 hosts

   There are a total of 148 hosts in all. Give a possible arrangement of subnet masks to make this possible.
Problem: CM21  
Area: Security and Reliability  

Answer all five of the questions below.

1. What is the difference between a one-way hash function and a message authentication code?
2. Why is it preferable to generate a signature before applying compression?
3. What is the difference between symmetric and asymmetric encryption? Which technique is preferable, and why?
4. Describe two types of attacks that can be addressed by message authentication and explain how message authentication addresses them.
5. You are comparing two different encryption techniques. How can you tell which one achieves better diffusion? Justify your answer.
Problem: CM22

Area: Security and Reliability

Suppose you have a true random bit generator where each bit in the generated stream has the same probability of being a 0 or 1 as any other bit in the stream and that the bits are not correlated; that is, the bits are generated from identical independent distributions. However, the bit stream is biased. The probability of a 1 is $0.5 + \delta$, where $0 \leq \delta \leq 0.5$. A simple deskewing algorithm is as follows: Examine the bit stream as a sequence of nonoverlapping pairs. Discard all 00 and 11 pairs. Replace each 01 pair with 0 and each 10 pair with 1. Answer all three questions below. Justify your answers.

a. What is the probability of occurrence of each pair in the original sequence?
b. What is the probability of occurrence of 0 and 1 in the modified sequence?
c. Suppose that the algorithm uses overlapping successive bit pairs instead of non-overlapping successive bit pairs. That is, the first output bit is based on input bits 1 and 2, the second output bit is based on input bits 2 and 3, and so on. What can you say about the output bit stream?
Problem: CM23  
Area: Security and Reliability  
Code #__________

Use the function table and assumed fault set $F$ shown below to determine the following. Note that only one fault from the fault set can occur at a time.

<table>
<thead>
<tr>
<th>Cubes</th>
<th>Input</th>
<th>Output</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A$</td>
<td>$B$</td>
<td>$X$</td>
</tr>
<tr>
<td>C0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

$F = \{A_{b=0}, A_{b=1}, B_{b=0}, B_{b=1}\}$

a. (10pts) Does this combinational circuit have "self-testing" property? Explain why or why not using examples.

b. (10pts) Does this combinational circuit have "fault-secure" property? Explain why or why not using examples.
Problem: CM24  
Area: Security and Reliability  
Code #__________

An NMR system consists of five identical computing modules and a voter. Assume the reliability of the voter is much more reliable than the modules and can be neglected. Determine the following.

a. (5pts) Find the reliability of the module \( R_m \) and the reliability of the NMR system \( R_{NMR} \) using the exponential failure law.

b. (10pts) Assume that an individual module fails every 10,000 hours. Find the Reliability Improvement Factor (RIF) at \( t = 5,000 \) hours.

c. (10pts) Consider a Hybrid Redundancy system consists of a TMR system with two dynamic spares (e.g., (3,2) system). Compare \( R_{NMR} \) and \( R_{HYBRID} \), assuming that an individual module fails every 10,000 hours and \( t = 5,000 \). Which one is better in terms of the reliability?
A recursive procedure solves a problem of size \( n \) by calling itself \( n - 1 \) times on \( n-1 \) sub-problems, where the \( i^{th} \) sub-problem has size \( i \). Then the answers are combined in unit time. That is, let \( T(n) \) be the running time of the procedure when it solves a problem of size \( n \), then we have the following recurrence:

\[
T(n) = \begin{cases} 
1 & n = 1 \\
1 + \sum_{i=1}^{n-1} T(i) & n > 1 
\end{cases}
\]

Solve the above recurrence exactly, and prove the correctness of your answer by induction.
Given two sorted arrays of integers denoted by $A$ and $B$, give an efficient solution to find the median of $A \cup B$. 
Prove by mathematical induction that $\forall n \in \mathbb{Z}, n \geq 4, n! > n^2$
Prove, formally, whether the following are True or False; show your work.

a. \( \log_2 n \) is \( \Theta(\log_3 n) \)

b. \( \sum_{i=1}^{n} 5ni \) is \( \Theta(n^3) \)