1. Assume a program requires the execution of $25 \times 10^6$ FP instructions, $110 \times 10^6$ INT instructions, $80 \times 10^6$ L/S instructions, and $16 \times 10^6$ branch instructions. The CPI for each type of instruction is 2, 1, 4, and 2, respectively. Assume that the processor has a 2 GHz clock rate.
   (a) What are the clock cycles of the program? (5%)
   (b) If we want the program to run two times faster, what should the CPI of L/S instructions be? (5%)
   (c) What is the execution time of the program if the CPI of INT and FP is reduced by 40% and the CPI of L/S and Branch is reduced by 30%? (5%)

2. Assume that individual stages of the datapath have the following latencies:

<table>
<thead>
<tr>
<th></th>
<th>IF</th>
<th>ID</th>
<th>EX</th>
<th>MEM</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250ps</td>
<td>360ps</td>
<td>150ps</td>
<td>300ps</td>
<td>200ps</td>
</tr>
</tbody>
</table>

Also, assume that instructions executed by the processor are broken down as follows:

<table>
<thead>
<tr>
<th></th>
<th>alu</th>
<th>beq</th>
<th>lw</th>
<th>sw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>50%</td>
<td>20%</td>
<td>15%</td>
<td>15%</td>
</tr>
</tbody>
</table>

   (a) What is the clock cycle time in a pipelined processor? What is the clock cycle time in a non-pipelined processor? (4%)
   (b) What is the total latency of an LW instruction in a pipelined processor?
       What is the total latency of an LW instruction in a non-pipelined processor? (6%)
   (c) If we can split one stage of the pipelined datapath into two new stages, each with half the latency of the original stage, which stage should be split? What is the new clock cycle time of the processor? (4%)
   (d) Assuming there are no stalls or hazards, what is the utilization of the data memory? (3%)
   (e) Assuming there are no stalls or hazards, what is the utilization of the write-register port of the “Registers” unit? (3%)

3. The following problems are related to postfix notation of expressions:
   (a) Give the postfix form of the following expression: (3%)
       $(A - B) * ((C + D) / (E - F))$
   (b) Consider the postfix-form expression: $ABC + DE - F */ -. If the values of the operands are as follows: $A = 32, B = 4, C = 3, D = 13, E = 1, F = 3$, what is the result obtained when evaluating the expression? (4%)
4. The figure below illustrates a binary search tree in which there are 13 distinct elements. Note that the letters in the nodes of the tree are simply used for identifying the corresponding elements. The keys of the elements (nodes) are not explicitly shown in the figure.

```
A
 / \
B   C
 / \ / \ / \
D E F I K J
 G H Y Z
```

(a) How many elements are there in the tree that have keys that are smaller than the key of node P? (5%)
(b) Which node contains the element with the 5th largest key? (5%)
(c) What is the minimum height of a binary search tree that can be constructed to contain the same set of elements as given in the figure? (A tree with a single node has a height of one.) (3%)

5. If we traverse a binary search tree recursively in the following order:
   (1) traverse the right subtree
   (2) visit the root
   (3) traverse the left subtree
   what is the order produced by such a traversal? (5%)

6. Express the time complexity of the following code segments in terms of $n$ using the $O$ notation.
   (a) (5%)
   ```
   int result=0, n;
   int i=1, j;
   while (i<=n) {
       for (j=1; j<=n; j*=2)
       result = result + i*j;
       i++;
   }
   return result;
   ```
(b) (5%)
    int result=0, n;
    int i=1, j, m;
    m = n/2;
    while (i<=n) {
        for (j=1; j<=n; j+=2)
            if (j<m)
                result = result + i*j;
            else
                result = result + 2*i*j;
        i++;
    }
    return result;

7. Consider a hard drive of moving-head mechanism. Given that the current head position is at cylinder 119, the disk arm is moving toward 0, and disk read requests on cylinders 88, 168, 37, 117, 14, 124, 65, and 67 are pending. Moreover, a new request at cylinder 99 interrupts right before the 3rd reading finishes and the requests in queue are then rescheduled with this new request. Determine the sequence of cylinders the head visits for the following disk-scheduling algorithms:
   (a) SSTF (4%)
   (b) SCAN (4%)
   (c) C-LOOK (4%)

8. If the shell command
   ```bash
   # ls -l exec.out
   ```
   in a Linux terminal produces the following output:
   ![Output Image]
   (a) Assume that you have logged in as the normal user os, input one command to make this file an executable one to all users. (3%)
   (b) Consider (a) is done. Assume that the current working directory is not included in the search path, input one command to execute this file. (2%)
   (c) Input one command to execute this file as root. (2%)

9. Define buffer-overflow attack and explain how it works. (6%)

10. The heartbeat procedure is commonly used in distributed systems to detect link and site failure. Suppose that site A and B have established a connection of some network service, describe how site A may execute the heartbeat procedure to make sure that the connection is alive. (5%)