1) Given a binary tree, write a function that returns the number of nodes in the tree that have exactly one child.
Notes:
The function should have just one argument, a pointer to the root.
No global variables may be used.
No additional functions may be defined.

2) Consider the following insertion sort algorithm.

```c
void insertion_sort(element a[], int n)
// Put a[0]..a[n-1] into ascending order by insertion sort.
{
    for (int k = 1; k < n; k++) {
        // At this point, a[0]..a[k-1] are already in order.
        // Insert a[k] where it belongs among a[0]..a[k].
        // You need to write code for this insertion as the body of the for-k loop.
    }
}
```

a) Write the code for the body of the for-k loop to complete the insertion sort routine.
b) Count the precise best case and worst case number of “element comparisons” in your insertion sort routine. Your answers should be functions of n in closed form. Note that “closed form” means that you must resolve all sigmas and …’s. Asymptotic answers (such as ones that use big-oh, big-theta, etc.) are not acceptable.

3) Which of the following five statements correctly describes the relationship between the functions f and g defined in a)-d) below? Note that more than one of the five statements may be correct for each part. You do not need to explain your choices.

\[
f \in o(g) \quad f \in O(g) \quad f \in \Theta(g) \quad g \in o(f) \quad g \in O(f)
\]

a) \( f(n) = 3n^2, \quad g(n) = 2n^2 \)
b) \( f(n) = 2^n, \quad g(n) = 3^n \)
c) \( f(n) = 2^{n-1}, \quad g(n) = 2^n \)
d) \( f(n) = \sqrt{n}, \quad g(n) = \log_2(n) \)
SYSTEMS EXAM
Spring 2020
90 minutes

Check which problems you are submitting:

☐ #1
☐ #2
☐ #3

How many pages total?______
Please do not write on the back of any pages.

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(print name)

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(signature)

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(NetId)
CS 692 Capstone Exam – Systems Spring 2020

Directions: Choose only two out of the three problems listed below. If you attempt all three, only questions one and two will be graded. A score of 24/40 is needed to pass the test. Please show all work.

1) CPU Scheduling
   a. (6pts) What are the possible states of a process? Draw a diagram and label transitions.
   
   b. (3pts) Indicate which of the following are shared by threads? Code, stack, data, register set, file pointers.

   a. (8pts) Below is a set of processes with CPU burst times listed in milliseconds. Draw a Gantt chart for the preemptive Shortest Remaining Time First scheduling algorithm. Label the ending times of each process.

<table>
<thead>
<tr>
<th>Process</th>
<th>Arrival Time</th>
<th>CPU burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>P2</td>
<td>3</td>
<td>5</td>
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<tr>
<td>P3</td>
<td>5</td>
<td>6</td>
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<tr>
<td>P4</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>P5</td>
<td>10</td>
<td>4</td>
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</tbody>
</table>

   b. (3pts) What is the definition of average turnaround time? What is the value of average turnaround time in this problem?

2) Dining Philosophers
   a. (2pts) The term for when a process is denied necessary resources indefinitely is: (Circle your answer).

      a) latency    b) starvation  c) inversion    d) aging

   b. (4pts) List the four standard, necessary conditions of deadlock.
c. (4pts) Describe an option for recovering from deadlock.

d. (2pts) Consider the solution below to the dining philosopher’s problem. There are 7 philosophers. (Philosopher i where \( i = 0, 1, 2, \ldots 6 \)). Semaphores are initialized to 1. Can deadlock occur?

(4pts) Explain or give a sequence of events that prove your answer to part d above.

```c
while (true){
    think;
    wait(mutex);
    wait fork[i];
    wait fork[(i+1) %7]
    signal(mutex);
    eat;
    signal(fork[i]);
    signal(fork[(i + 1) %7];
}
```

e. (4pts) The function wait is implemented with a Last In First Out queue (LIFO). Can starvation occur? Explain or give a sequence of events that prove your answer.

3) Memory

a. (4pts) Explain how first fit and best fit memory allocation work. Give one advantage and one disadvantage of each of these allocation methods.

b. (4pts) What is meant by the term thrashing? Describe one mechanism for solving this problem which uses memory efficiently.

3c. Page replacement – using the 2nd chance algorithm. Assume 3 page frames have been allocated to a process.

(8pts) Show the contents of the page frames and the reference bits after every page access for the following list of page requests: 1, 2, 3, 4, 2, 5, 6, 4, 3, 3, 2, 6. In addition, indicate when a page fault has occurred.
(4pts) Repeat using the **optimal** algorithm.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
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Theory Exam

Answer ANY TWO of the following three questions:

1. Give the state diagram for a pushdown automaton (PDA) that recognizes the following language over \( \Sigma = \{0, 1, \#\} \):

\[ \{w_1\#w_2 : w_1, w_2 \in \{0, 1\}^* \text{ and } |w_1| > |w_2|\} \]

In English: two substrings separated by \# where the first substring is longer than the second.

2. Give the state diagram for a deterministic Turing machine that decides the following language over \( \Sigma = \{0, 1\} \):

\[ L = \{w : w \text{ contains both the substrings 011 and 110}\} \]

Use ONLY the following notation to label each of your machine’s transitions:

\[ q_i \xrightarrow{\alpha \to \beta, \text{move left}} q_j \]

OR

\[ q_i \xrightarrow{\alpha \to \beta, \text{move right}} q_j \]

3. A clique in an undirected graph is a collection of vertices that are fully interconnected by edges. Consider the following language:

\[ \text{CLIQUE} = \{G, k : G = (V, E) \text{ is an undirected graph containing a clique of at least size } k\} \]

Prove that \( \text{CLIQUE} \in \text{NP} \).

NOTE THE FOLLOWING:
You are being asked to prove that \( \text{CLIQUE} \) is in \( \text{NP} \), and not that \( \text{CLIQUE} \) is \( \text{NP-Complete} \! \). No definitions or discussions required, and will earn no points.