

1 Graph Conceptuals

- (a) Answer the following questions as either **True** or **False** and provide a brief explanation:
1. If a graph with n vertices has $n - 1$ edges, it **must** be a tree.
 2. Every edge is looked at exactly twice in **every** iteration of DFS on a connected, undirected graph.
 3. In BFS, let $d(v)$ be the minimum number of edges between a vertex v and the start vertex. For any two vertices u, v in the fringe, $|d(u) - d(v)|$ is **always less than 2**.
- (b) Given an directed graph, provide an algorithm that returns true if a cycle exists in the graph, and false otherwise. Also, provide a Θ bound for the worst case runtime of your algorithm.

2 Fill in the Blanks

Fill in the following blanks related to min-heaps. Let N is the number of elements in the min-heap. For the entirety of this question, assume the elements in the min-heap are **distinct**.

1. `removeMin` has a best case runtime of _____ and a worst case runtime of _____.
2. `insert` has a best case runtime of _____ and a worst case runtime of _____.
3. A _____ or _____ traversal on a min-heap *may* output the elements in sorted order. Assume there are at least 3 elements in the min-heap.
4. The fourth smallest element in a min-heap with 1000 elements can appear in _____ places in the heap.
5. Given a min-heap with $2^N - 1$ distinct elements, for an element
 - to be on the second level it must be less than _____ element(s) and greater than _____ element(s).
 - to be on the bottommost level it must be less than _____ element(s) and greater than _____ element(s).

Hint: A complete binary tree (with a full last-level) has $2^N - 1$ elements, with N being of levels.

3 Heap Mystery

We are given the following array representing a min-heap where each letter represents a **unique** number. Assume the root of the min-heap is at index zero, i.e. A is the root. Note that there is **no** significance of the alphabetical ordering, i.e. just because B precedes C in the alphabet, we do not know if B is less than or greater than C.

Array: [A, B, C, D, E, F, G]

Four unknown operations are then executed on the min-heap. An operation is either a `removeMin` or an `insert`. The resulting state of the min-heap is shown below.

Array: [A, E, B, D, X, F, G]

- (a) Determine the operations executed and their appropriate order. The first operation has already been filled in for you!

1. `removeMin()`
2. _____
3. _____
4. _____

- (b) Fill in the following comparisons with either $>$, $<$, or $?$ if unknown. We recommend considering which elements were compared to reach the final array.

1. X _____ D
2. X _____ C
3. B _____ C
4. G _____ X