General Instructions

1. You may use any printed/written material. Electronic devices are not allowed.

2. The work is to be your own and you are expected to adhere to the UMass Boston honor system.

3. The exam contains 5 questions. The weight of each question is listed. **Read each question carefully before you answer.**

4. Write your answers in the available spaces, using the back of the page if needed. Write clearly and concisely and try to avoid cursive.

5. Please explain your answers if needed **but do it briefly.**

6. If you base your answer on a homework question or class notes state it in your answer.

Good Luck!

Name (as appears in your student ID): ______________________

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1. (20%) Runtime analysis. Given the following piece of code:

```java
class Mystery {
    public static void mystery(int n) {
        if (n == 1) {
            System.out.println("Something");
        } else {
            System.out.println("Something");
            mystery(n / 2);
        }
    }
}
```

Let $T(n)$ be the running time of mystery in terms of its argument $n$.

a. (5%) write the $T(n)$ formula as shown in class and explain briefly.

b. (5%) What is the runtime of this function based on the $T(n)$ formula you derived?

c. (5%) Exactly how many times will “Something” be printed for $n = 7$?

d. (5%) This part is unrelated to (a-c) above. A given algorithm runs as $O(2^n)$ where $n$ is the input size. If the algorithm takes 10 seconds to run on an input of size 5, what is the input size that makes the algorithm run for approximately 40 seconds? Explain.
2. (25%) Java implementation and collections: For each of the following statements say whether it is possible or not using only the API collections we learned in class. Explain each answer briefly.

(a) (5%) A program has set up a Map from String to Integer, i.e. Map<String, Integer>. Now it wants to make two different keys, “x” and “y” map to the same Integer 6.

(b) (5%) A program has set up a Map from String to Integer. Now it wants to set up the inverse map from Integer to String. Can it just allocate a new Map<Integer,String> get all the HashEntries from the original map, reverse the role of key and value and insert it to the new map, such that all the original data is retained?

(c) (5%) A program has set up a List of integers, List<Integer>, and added several elements to it. Now it wants to determine the smallest number in less than $O(n)$ time.

(d) (5%) Same as (c) above only using a HashSet<Integer>.

(e) (5%) Same as (c) above only using a TreeSet<Integer>.
3. Hash tables (15%): In each one of the following questions provide a brief explanation (no more than a sentence or two).

(a) (5%) Let $H$ be a hash table where collisions are handled by separate chaining. Re-hashing is used whenever the load factor (ratio of items in the table and the size of the table) exceeds $\frac{1}{2}$. Assume that the initial size of $H$ is 2 and re-hashing doubles the size of the table. After inserting 10 items with different keys, what is the size of $H$?

(b) (5%) Consider a hash table $H$ that uses separate chaining to resolve collisions. Moreover, when adding a new element to an entry’s linked list, such an element is inserted in the beginning of the list. What is the worst-case time complexity (big-Oh) to insert $n$ keys into the table?

(c) (5%) In the hash table in (b) above, what would be the worst case run time if we maintained every entry as a sorted data structure, say a TreeSet (the sorting is by key)?
4. Induction (25%). Prove the following formulas. Don’t forget to explicitly state the three stages:

- Base case
- Inductive hypothesis for $1 < k < n$
- The inductive step from $n - 1 \rightarrow n$ (or $n \rightarrow n + 1$ if it works better)

(a) (13%) For all $n \geq 1$, show that $n^3 + 2n$ is divisible by 3.
   For your convenience, $(n + 1)^3 = n^3 + 3n^2 + 3n + 1$.

(b) (12%) Show that every tree with $n$ nodes has exactly $n-1$ edges. You may define a tree as an undirected connected graph with no cycles.
   **Hint:** In the inductive step, instead of adding a node to a tree of size $n-1$, start from a non-empty tree of size $n$ and remove an edge from it.
5. Graphs (25%):

(a) (13%) There are two types of professional wrestlers: "babyfaces" ("good guys") and "heels" ("bad guys"). Between any pair of professional wrestlers, there may or may not be a rivalry. Suppose we have \( n \) professional wrestlers and we have a list of \( r \) pairs of wrestlers for which there are rivalries. Give an \( O(n + r) \) time algorithm that determines whether it is possible to designate some of the wrestlers as babyfaces and the remainder as heels such that each rivalry is between a babyface and a heel. If it is possible to perform such a designation, your algorithm should produce it. You may re-use any algorithm we learned in class as-is (without re-writing all the stages).

b. (12%) Trace the run of Depth-First search (DFS) algorithm starting from \( v_1 \) in the graph below. For tracing, use the same notation as in the class notes and HW3 solutions. In case of multiple options follow numerical order. Mark an * near the edges that participate in the final tree.

```
  v1
 /    /
v2  v3    v4
  |    |
  v5   v6
```