This test has 9 questions worth a total of 45 points, and is to be completed in 110 minutes. The exam is closed book, except that you are allowed to use two double-sided page of notes as a cheat sheet (front and back). No calculators or other electronic devices are permitted. Give your answers and show your work in the space provided.

Write the statement out below in the blank provided and sign. You may do this before the exam begins. Any plagiarism, no matter how minor, will result in points deducted from your exam.

“I have neither given nor received any assistance during the taking of this exam.”

_______________________________________________________________________________________

Signature: _______________________________

Write your name and student ID on the front page. Write the names of your neighbors. Write and sign the above statement. Once the exam has started, write your class ID in the corner of every page.

Name: __________________________ Your Class ID: ______
SID: __________________________ Name of person to left: __________________________
TA: __________________________ Name of person to right: __________________________

Tips:
• There may be partial credit for incomplete answers. Write as much of the solution as you can, but bear in mind that we may deduct points if your answers are much more complicated than necessary.
• There are a lot of problems on this exam. Work through the ones with which you are comfortable first. Do not get overly captivated by interesting design issues or complex corner cases you’re not sure about.
• Not all information provided in a problem may be useful.
• Unless otherwise stated, all given code on this exam should compile. All code has been compiled and executed before printing, but in the unlikely event that we do happen to catch any bugs during the exam, we’ll announce a fix. Unless we specifically give you the option, the correct answer is not ‘does not compile.’
• ○ indicates that only one circle should be filled in.
• □ indicates that more than one box may be filled in.
• For answers that involve filling in a ○ or □, please fill in the shape completely.

Optional. Mark along the line to show your feelings Before exam: [○________________________] on the spectrum between ○ and ☺. After exam: [☺________________________].
Reference Material

/** Collections */
All Collections implement Iterable and have size(), isEmpty() and stream() methods.

```java
public class HashSet<T> {
    void add(T item);
    boolean contains(T item);
}

public class TreeSet<T extends Comparable<T>> {
    void add(T item);
    boolean contains(T item);
}

public class LinkedList<T> implements Queue<T> {
    void addFirst(T item);
    void addLast(T item);
    T get(int index);
    T removeFirst();
    T removeLast();
}

public class Stack<T> {
    void push(T item);
    T pop();
}

public interface Queue<T> {
    void offer(T e);
    T poll();
    T peek();
}
```
/** Maps */

public class HashMap<K, V> {
    void put(K key, V value);
    V get(K key);
    boolean containsKey(K key);
}

public class TreeMap<K extends Comparable<K>, V> {
    void put(K key, V, value);
    V get(K key);
    boolean containsKey(K key);
}

/** Streams */

public interface Stream<T> {
    Stream<T> filter(Predicate<? super T> predicate);
    <R> Stream<R> map(Function<? super T, ? extends R> mapper);
    Optional<T> reduce(BinaryOperator<T> accumulator);
    Stream<T> sorted(Comparator<? super T> comparator);
    void forEach(Consumer<? super T> action);
    <R, A> R collect(Collector<? super T, A, R> collector);
}

public class Collectors {
    static <T> Collector<T, ?, List<T>> toList();
    static <T> Collector<T, ?, Set<T>> toSet();
    static <T,K> Collector<T, ?, Map<K, List<T>>>
        groupingBy(Function<? super T, ? extends K> classifer);
}

public class Optional<T> {
    boolean present();
    T orElse(T other);
}
1. Stark: Winter is Coming (6 pts)

a. Draw the result of deleting 10 from the BST below using the standard deletion algorithm outlined in lab.

```
Original

    10
   /   \
  6     15
 /   \   /   \
3     9  13    21
    / \      \
   7   11     12

delete(10)
```

b. Draw the splay tree below after find(7) has been called.

```
Original

    15
   /   \
  13    16
 /   \   /   \
10    14  18
 / \   /   \
5    8  17
     /   \
    7

find(7)
```
c. Draw the result of inserting 20 into the following **2-3-4 tree** using the insertion algorithm discussed in lab. Afterwards, draw the **red-black tree** that corresponds to the resulting 2-3-4 tree. **Clearly mark red nodes with the letter R to the right of the number.**

<table>
<thead>
<tr>
<th>Original</th>
<th>insert(20)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Original Tree" /></td>
<td><img src="image" alt="Red-Black Tree" /></td>
</tr>
</tbody>
</table>

**Red-black tree that corresponds to the 2-3-4 tree after insert(20)**
2. Tully: Family, Duty, Honor (6 pts)

Consider the following “real-world” situations. For each situation, select the data structure that would be best suited in terms of performance and ease-of-use, taking into consideration the specific types of inputs listed in each problem. Give a brief and succinct justification (2 lines or less) for why that data structure is best suited. You may assume the LinkedList is a circular doubly-linked list with a sentinel node. Using Big-Theta notation, give the worst-case runtime bound of using your data structure with respect to the variables defined in each part. If there is more than one possible answer, choose only one data structure.

You may assume the LinkedList is a circular doubly-linked list with a sentinel node. Using Big-Theta notation, give the worst-case runtime bound of using your data structure with respect to the variables defined in each part. If there is more than one possible answer, choose only one data structure.

a. Kai has been tasked with scheduling autograder jobs in the order in which they arrive. He receives jobs one by one from the Professor Pretentious and must be able to provide the next job to the autograder when one is requested, removing that job from the pool of waiting jobs in the process. You may assume that there are never more than \( N \) jobs waiting at once. Choose the best data structure to store the waiting jobs in.

| ○ Array | ○ LinkedList | ○ Red-Black Tree | ○ Splay Tree | ○ HashSet |

Justification:

________________________________________________________________________

Runtime (Schedule a job): _______________ Runtime (Get next job to run): _______________

b. Sarah has become the CEO of MeTube and wants a way to store the number of visits that various websites have. She wishes to construct a data structure that contains her websites and query this data structure for the top \( K \) most-visited websites. At any given moment, she may receive a new website along with its number of visits, thus forcing Sarah to update the data structure. Once a site is added, its number of visits cannot be updated. Choose the best data structure to store the websites. You may assume there are never more than \( N \) websites indexed at once and that query operations are much more common than add operations.

| ○ Array | ○ LinkedList | ○ Red-Black Tree | ○ Splay Tree | ○ HashSet |

Justification:

________________________________________________________________________

Runtime (Add one website): _______________ Runtime (Query): _______________


c. You are in charge of storing a set of \( N \) student names on \textit{PandaGrade}. When a user logs into \textit{PandaGrade}, you must check that the user’s name is in the set of student names. A small set of \textit{PandaGrade} users typically make up the vast majority of login requests (since a few students use \textit{PandaGrade} to submit a lot of regrade requests). In addition to checking for membership of users’ names in the set of student names, we’d like to be able to produce a sorted list of student names. Choose the best data structure to handle these operations.

| Array | LinkedList | Red-Black Tree | Splay Tree | HashSet |

**Justification:**

__________________________________________________________________________________________

Runtime (Check that user is a student): ___________  Runtime (Get sorted student list): ___________

d. Kevin wants to be more spontaneous. So, he decides to make sure that he never visits the same \textit{Restaurant} twice. Choose a data structure to store each new \textit{Restaurant} that Kevin visits. At any time, Kevin must be able to check if a given \textit{Restaurant} has been visited. You can assume that Kevin will never visit more than \( N \) \textit{Restaurants}.

| Array | LinkedList | Red-Black Tree | Splay Tree | HashSet |

**Justification:**

__________________________________________________________________________________________

Runtime (Insertion): _________________  Runtime (Query): _________________

Chocobo says hi
3. Arryn: As High As Honor (3 pts)

Consider the Widget class below. You may assume the HashSet class uses external chaining and the bucket-indexing formula discussed in class. HashSet stores no duplicates. HashSet has a maximum load factor of .75; it doubles in size when there are more than .75 items per bucket on average in the set.

```
public class Widget {
    Integer doohickey;

    public Widget(Integer doohickey) {
        this.doohickey = doohickey;
    }

    public int hashCode() {
        return 1;
    }

    public boolean equals(Object o) {
        return true;
    }

    public static void hashParty(int M) {
        HashSet<Widget> pad = new HashSet<>();
        for (int i = 0; i < M; i++) {
            pad.add(new Widget(i));
        }
    }
}
```

a. Using Big-Theta notation, provide the worst-case runtime bound for hashParty in terms of its argument M.

Worst case: ______

b. Now, suppose we replace Widget’s equals method above with the following:

```
public boolean equals(Object o) {
    return false;
}
```

Using Big-Theta notation, provide the new worst-case runtime bound for hashParty, again in terms of M. The new runtime may be the same as before.

Worst case: ______
c. Finally, suppose we replace Widget's equals and hashCode methods as follows:

```java
public int hashCode() {
    return this.doohickey;
}

public boolean equals(Object o) {
    return false;
}
```

Using Big-Theta notation, provide the new worst-case runtime bound for hashParty, again in terms of $M$. The new runtime may be the same as before.

Worst case: ______

---

**Designated Drawing Space**

Maybe take a second to breathe and draw a Moogles for the Moogles below. He wants a friend.
4. Tyrell: Growing Strong (4 pts)

Consider the Patriot class below:

```java
public class Patriot {
    public String name;
    public int intellect;
    public int wisdom;
    public Patriot(String name, int i, int w) {
        this.name = name; this.intellect = i; this.wisdom = w;
    }
    public int hashCode() {
        return intellect;
    }
    public boolean equals(Object o) {
        if (o instanceof Patriot) { 
            Patriot other = (Patriot) o;
            return intellect == other.intellect
                && name.equals(other.name);
        }
        return false;
    }
}
```

You now execute the following lines of code:

```java
Patriot ham = new Patriot("Hamilton", 32, 15);
Patriot burr = new Patriot("Burr", 19, 10);
Patriot adams = new Patriot("Adams", 24, 12);
HashMap<Patriot, Patriot> enemyMap = new HashMap<>();
enemyMap.put(ham, burr);
enemyMap.put(burr, ham);
enemyMap.put(adams, ham);
```

Finally, you now consider the following four code snippets, each executed independently after the snippet above. For each snippet, write what is printed. If the snippet produces a NullPointerException, write NullPointerException and justify your answer. No justification is necessary if a NullPointerException is not thrown. None of the following code snippets produce compiler errors, nor do they produce runtime errors other than NullPointerException.

You may assume the HashMap class uses external chaining and the bucket-indexing formula discussed in class. It stores no duplicates. HashMap initially has **16 buckets and a load factor of .75**. The HashMap doubles in size when there are more than .75 items per bucket on average in the table. You may assume HashMap's get method returns null when the provided key argument is not in the map.
ham.intellect = 33;
System.out.println(enemyMap.get(burr).name);

Print Output: _______________________________________
Justification: __________________________________________

adams.intellect = 26;
System.out.println(enemyMap.get(adams).name);

Print Output: _______________________________________
Justification: __________________________________________

ham.wisdom = 8;
System.out.println(enemyMap.get(ham).name);

Print Output: _______________________________________
Justification: __________________________________________

ham.intellect = 16;
System.out.println(enemyMap.get(ham).name);

Print Output: _______________________________________
Justification: __________________________________________

0. PNH (0 pts)
This author won the Nobel Prize in Literature for creating “an imagined world, where life and myth condense to form a disconcerting picture of the human predicament today.”
5. Baratheon: Ours is the Fury (5 pts)

For each of the methods below, bound the runtime of the method using Big-Theta notation in terms of the input N. If not possible, write N/A. For full credit, your answer should be as simple as possible with no unnecessary leading constants or lower order terms.

```
private static void f(int N) {
    if (N < 1) {
        return;
    }
    f(N/2);
}
```

```
private static void g(int N) {
    if (N < 1) {
        return;
    }
    g(N - 1);
}
```

```
private static void h(int N) {
    if (N < 1) {
        return;
    }
    h(N/2);
    h(N/2);
    h(N/2);
    h(N/2);
}
```

```
private static void combined(int N) {
    for (int i = 1; i < N; i *= 2) {
        constant(N); // runs in constant time with respect to input
        linear(N); // runs in linear time with respect to input
        quadratic(N); // runs in quadratic time with respect to input
    }
}
```

```
private static void challenge(int N) {
    for (int i = 1; i < N; i *= 2) {
        // runs in logarithmic time with respect to input
        logarithmic(i);
    }
}
```
6. Lannister: Hear Me Roar (3 pts)

Consider the heavily redacted Commit class below. Commit objects contain a nameToSHA HashMap. nameToSHA contains a mapping of the names of the files tracked by this Commit to the hashes of the blob backups corresponding to those files. You may not assume anything about Commit's instance variables or methods other than that which is provided below. Fill in the isFilePresent method so that the method behaves according to its comment. You may assume the Utils class is available to the Commit class (via import or otherwise).

```java
public class Commit {
    ...
    /**
     * A map of filename strings to the SHA-1 strings of those files'
     * contents.
     */
    public HashMap<String, String> nameToSHA;

    /**
     * Returns true if
     * a) given filename is tracked by this commit and
     * b) given contents matches the contents of this commit's blob for filename
     * with high probability.
     * Otherwise, returns false.
     */
    public boolean isFilePresent(String filename, byte[] contents) {
        if (______________________________________________) {
            ______________________________________;
            ______________________________________;
        }
        ______________________________________;
    }
}

public class Utils {
    ...
    /** Returns the SHA-1 hash of a byte array. */
    public static String sha1(byte[] content) { ... }
}
```
7. Greyjoy: We Do Not Sow (6 pts)

A NestedList is a list that contains either a char, or a List of NestedLists. Given a NestedList, complete the DeepIterator, an iterator that returns each char in the NestedList in order (essentially flattening the NestedList).

For example, given the NestedList: [[e], [[x], [o]]], a series of next() calls should return e, x, o. (.) denotes a List and [] denotes a NestedList. A NestedList can be arbitrarily deep (i.e. you could have to go through many lists before you get to a char). You may assume that the user of the iterator will always call hasNext() before next().

```java
import java.util.List;
import java.util.Stack;

public interface NestedList {
    /**
     * Returns true if this NestedList holds a single char,
     * false if it contains a list of NestedLists.
     */
    public boolean isChar();

    /**
     * Returns the single char that this NestedList holds,
     * if it holds a single char, otherwise returns null.
     */
    public Character getChar();

    /**
     * Returns the List of NestedLists that this NestedList holds,
     * if it holds a List. Otherwise, returns null.
     */
    public List<NestedList> getList();
}

public class DeepIterator implements Iterator<Character> {
    Stack<NestedList> stack = new Stack<>();

    public DeepIterator(NestedList list) {
        //
    }

    // (continued on next page)
```
```java
@Override
public boolean hasNext() {
    ______________________________;
}

@Override
public Character next() {
    while(!stack.isEmpty()) {
        NestedList curr = ______________________________;
        if(______________________________) {
            ______________________________;
        }
        ______________________________;
        for(__________; _______________; ____________) {
            ______________________________;
            ______________________________;
        }
    }
    return null;
}
```
8. Martell: Unbowed, Unbent, Unbroken (6 pts)

a. You are given a list of Users as defined below. Using streams, complete the methods such that they work as specified by their comments. Each method requires only a single statement (one semicolon only).

```java
public class User {
    ...
    public User(int age, String name) { ... }
    public List<User> getFriends() { ... }
    public int getAge() { ... }
    public String getName() { ... }

    /** Returns a List of the names of Users with age > 18. */
    public static List<String> olderThan18(List<User> lst) {
        return ________________________________;
    }

    /** Returns a list of Users ordered from least to most friends. */
    public static List<User> orderedByPopularity(List<User> lst) {
        return ________________________________;
    }
}
```

b. Write a method, functionReducer, which takes in a List of Functions and returns a single Function that is the composition of all the Functions in the list. For example, if the list contained $f(x)$, $g(x)$, and $h(x)$, `functionReducer` should return a function that would give the results of $f(g(h(x)))$. If the input list is empty, `functionReducer` should return null. This method requires only a single statement (one semicolon only).

Recall that a Function<T, R> takes in an argument of type T and returns an argument of type R. It is a functional interface that has a single apply method. Lambda statements and method references can be used in place of Functions.

```java
public static <T> Function<T, T> functionReducer(List<Function<T, T>> lst) {
    return ________________________________;
}
```
This page is left intentionally blank.

Continue forward young traveler.
A TrimTree is a binary tree that contains values of type T. When TrimTrees get too overgrown, they must be trimmed. We will trim a TrimTree *destructively* around the edges in a **bottom-up manner**.

Trimming a node N means removing both of its children and replacing N’s item with the result of the TrimTree’s combiner, called with N’s children passed as arguments. It is only possible to trim a node N if both of its children are leaves. To determine if a given node should be trimmed, a TrimTree has an isBetter predicate which will test to see if the current item of N is better than the result of combiner. Notice that when we trim a node N, it becomes a leaf and thus makes N’s parent available for trimming.

Complete the trim method on the next page, which does the work of recursively trimming the subtree rooted at a node. You may not need all lines. Each line should contain only one statement.

```java
import java.util.function.BiPredicate;
import java.util.function.BinaryOperator;

public class TrimTree<T> {
    /**
     * Has a test(T a, T b) method that returns true if a is better than b. */
    BiPredicate<T, T> isBetter;

    /**
     * Has an apply(T x, T y) method that returns some result of type T.
     * Input order does not matter.
     */
    BinaryOperator<T> combiner;

    TreeNode root;

    public TrimTree(BiPredicate<T, T> isBetter, BinaryOperator<T> combiner) {
        this.isBetter = isBetter;
        this.combiner = combiner;
    }

    private class TreeNode {
        T item;
        TreeNode left;
        TreeNode right;

        public TreeNode(T item, TreeNode left, TreeNode right) {
            ... }

        public TreeNode(T item) {
            ... }
    }
}
```

... (continued on next page)
private boolean isLeaf(TreeNode node) {
    return node != null && node.left == null && node.right == null;
}

public void trim() {
    root = trim(root);
}

private void trim(TreeNode node) {
    if (__________________________________________________)
        _____________________;
    _____________________________;
    _____________________________;
    if (__________________________________________________)
        _____________________;
        if (_______________________________________________)
            _____________________;
            _____________________;
            _____________________;
    }
    }
    }
}