In run, write what gets printed next to each line.

\( \text{x.a()} \) will call the \( \text{a()} \) according to the variable’s dynamic type.

\( \text{x.b()} \), because \( \text{b()} \) is not overridden, will use the \( \text{b()} \) in \text{Q}. Then, \( \text{b()} \) selects which \( \text{a()} \) to run based on the variable’s dynamic type.

\( \text{x.c()} \) runs \( \text{Q.c()} \), which runs \( \text{Q.e()} \). Note that \( \text{e()} \) is a static method, so it uses the static type to look up which function to call.

\( (\text{R}\ x).\ \text{c()} \) makes the same series of calls. Again, \( \text{e()} \) is a static method, so it uses the static type to look up which function to call.

\( \text{x.d()} \) runs \( \text{R.d()} \), which runs \( \text{R.e()} \).

\( (\text{R}\ x).\ \text{d()} \) makes the same series of calls.
2 Reduce

We’d like to write a method reduce, which uses a BinaryFunction interface to accumulate the values of a List of integers into a single value. BinaryFunction can operate (through the apply method) on two integer arguments and return a single integer. Note that reduce can now work with a range of binary functions (addition and multiplication, for example). Write two classes Adder and Multiplier that implement BinaryFunction. Then, fill in reduce and main, and define types for add and mult in the space provided.

```java
import java.util.ArrayList;
import java.util.List;
public class ListUtils {
    /** If the list is empty, return 0; if its one element, return it
     * Otherwise, apply a function of two arguments cumulatively to the
     * elements of list and return a single accumulated value. */
    public static int reduce(BinaryFunction func, List<Integer> list) {
        if (list.size() == 0) { return 0; }
        int soFar = list.get(0);
        for (int i = 1; i < list.size(); i++) {
            soFar = func.apply(soFar, list.get(i));
        }
        return soFar;
    }

    public static void main(String[] args) {
        ArrayList<Integer> integers = new ArrayList<>();
        integers.add(2); integers.add(3); integers.add(4);
        Adder add = new Adder();
        Multiplier mult = new Multiplier();
        reduce(add, integers); //Should evaluate to 9
        reduce(mult, integers); //Should evaluate to 24
    }
}

interface BinaryFunction {
    int apply(int x, int y);
}

//Add additional classes and interfaces below:
public class Adder implements BinaryFunction {
    public int apply(int x, int y) {
        return x + y;
    }
}

public class Multiplier implements BinaryFunction {
    public int apply(int x, int y) {
        return x * y;
    }
}
```

We declare an interface BinaryFunction which our Adder and Multiplier classes can implement. Writing a common interface is important, because it allows us to write a reduce function that is capable of accepting many kinds of functions. Note that interface methods are public by default, so apply must be public in Adder and Multiplier.
3 Comparator

We’d like to sort an ArrayList of animals into ascending order, by age. We can accomplish this using `Collections.sort(List<T> list, Comparator<? super T> c)`. Because instances of the Animal class (reproduced below) have no natural ordering, `sort` requires that we write an implementation of the Comparator interface that can provide an ordering for us.

Note that an implementation of Comparator only needs to support pairwise comparison (see the `compare` method). Remember that we would like to sort in ascending order of age, so an Animal that is 3 years old should be considered "less than" one that is 5 years old.

Note: for this question, you do not need to worry about implementing `equals`.

```java
public interface Comparator<T> {
    /** Compares its two arguments for order.
     * Returns a negative integer, zero, or a positive integer if the first
     * argument is less than, equal to, or greater than the second. */
    int compare(T o1, T o2);

    //** Indicates whether some other object is "equal to" this
    * comparator. */
    boolean equals(Object obj);
}
```

```java
import java.util.ArrayList;
import java.util.Collections;
public class Animal {
    private String name;
    private int age;
    public Animal(String name, int age) {
        this.name = name;
        this.age = age;
    }
    /** Returns this animal’s age. */
    public int getAge() {
        return this.age;
    }
    public static void main(String[] args) {
        ArrayList<Animal> animals = new ArrayList<>();
        animals.add(new Animal("Garfield", 4));
        animals.add(new Animal("Biscuit", 2));
        AnimalComparator c = new AnimalComparator(); //Initialize comparator
        Collections.sort(animals, c);
    }
}
```

```java
public class AnimalComparator implements Comparator<Animal> {
    public int compare(Animal o1, Animal o2) {
        return o1.getAge() - o2.getAge();
    }
}
```

We want to implement `Comparator<Animal>` because we are concerned with comparing objects of type Animal. Similarly, `compare` should take objects of type Animal. We would like
younger animals to be considered "less than" older animals, so in `compareTo` we can simply return 
\( o1.getAge() - o2.getAge() \) (this way, we return a negative integer if \( o1 \) is younger than \( o2 \), zero if the two animals are the same age, and a positive integer if \( o2 \) is younger than \( o1 \)). `Collections.sort`'s second argument is a `Comparator`, so we initialize our custom imple-
mentation on line 18 and pass it in on 19.
For this question, you do not need to worry about implementing `equals`, as the `equals` method 
on a `Comparator` allows you to indicate that one comparator provides the same ordering as another 
comparator - an extremely rarely needed functionality.

4 Midterm Practice

```java
public class PasswordChecker {
    /**
     * Asks you to login (by providing your username and password)
     */
    public void loginPrompt(User u) {
        u.login(this);
    }

    public boolean authenticate(String a, String b) {
        // Does something secret
    }
}

public class User {
    private String username;
    private String password;

    public void login(PasswordChecker p) {
        p.authenticate(username, password);
    }
}

public class PasswordExtractor extends PasswordChecker {
    String extractedPassword;

    public String extractPassword(User u) {
        u.login(this);
        return extractedPassword;
    }

    public boolean authenticate(String a, String b) {
        extractedPassword = b;
        return true; // or false. Just need to return something.
    }
}
```

By letting us subclass `PasswordChecker`, we can overwrite the `authenticate` method to 
capture the password in a local variable. By calling a user's `login` method and passing ourselves
in, we can force the user to provide its password. Finally, we can return the extracted password. We could fix this security hole by making `PasswordChecker` no longer a public class.