1 (8 marks)

(a) A *static* method is invoked on a(n) ....

Answer: class, or class name

Marking scheme: 4 marks for a correct answer, 0 marks otherwise.

(b) A *non-static* method is invoked on a(n) ....

Answer: object, or instance, or reference

Marking scheme: 4 marks for a correct answer, 0 marks otherwise.

2 (20 marks)

(a) What is the *state* of an object?

Answer: The values of all of its attributes.

Marking scheme: 4 marks for a correct answer, 0 marks otherwise.

(b) What is the *identity* of an object?

Answer: Its address, or some other unique identifier.

Marking scheme: 4 marks for a correct answer, 0 marks otherwise.

(c) What does the binary operator `==` check?

Answer: Equality of identity, or equality of value.

Marking scheme: 4 marks for a correct answer, 0 marks otherwise.

(d) What does the method `equals` check?

Answer: Equality of state.

Marking scheme: 4 marks for a correct answer, 0 marks otherwise.

(e) Consider the following fragment of Java code:

```
Fraction f1 = new Fraction(1, 2);
Fraction f2 = new Fraction(3, 4);
Fraction f3 = f1;
```

Circle the expressions below that evaluate to `true`:

[✓ `f1 == f1`]   `f1 == f2`   `f2 == f3`   [✓ `f1 == f3`]

[✓ `f1.equals(f1)`]   `f1.equals(f2)`   `f2.equals(f3)`   [✓ `f1.equals(f3)`]

Answers: Underlined above.

Marking scheme: 1 mark for each correct answer, −1 for each incorrect answer. Lowest possible total mark is 0.

3 (8 marks)

What are the *two* differences between a `Set` and a `List`?

Answer:

No duplicate elements allowed (`Set`) versus duplicate elements allowed (`List`).

Unordered (`Set`) versus sequential order (`List`); or only iterator-based access (`Set`) versus indexed-based access (`List`).

Marking scheme: 4 marks for each of the two differences.

4 (28 marks)

Consider the following fragment of (legal) Java code:

```
1 Number num = new BigInteger("123456789123456789");
2 double val = num.doubleValue();
3 num = ((BigInteger) num).subtract(new BigInteger("1"));
```

`BigInteger` extends `Number`.
The method `doubleValue()` is polymorphic.
The cast on line 3 is necessary for the code to compile.

(a) What class or classes are searched during early binding for the method `doubleValue()`? **Justify your answer**.

Answer: The declared type of `num` is `Number`; thus, early binding searches `Number`.

Marking scheme:

- 2 marks for mentioning the declared type
- 2 marks for the correct class (`Number`).

(b) What class or classes are searched during early binding for the method `subtract(BigInteger)`? **Justify your answer**.

Answer: The declared type of `num` is `Number`, which is cast to `BigInteger` for the invocation; thus, early binding searches `BigInteger`.

Marking scheme:

- 2 marks for mentioning the declared type
- 4 marks for mentioning the cast
- 2 marks for the correct class (`BigInteger`).

(c) What class or classes are searched during late binding for the method `doubleValue()`? **Justify your answer**.

Answer: The actual (or runtime) type of `num` is `BigInteger`; thus, late binding searches `BigInteger`.

Marking scheme:

- 6 marks for mentioning "actual type"
- 6 marks for identifying the actual type as `BigInteger`
- 4 marks for the correct class (`BigInteger`).

5 (4 marks)

Explain how composition differs from aggregation.

Answer: Composition is a stronger form of aggregation where the lifetime of the object and its aggregated objects are the same.

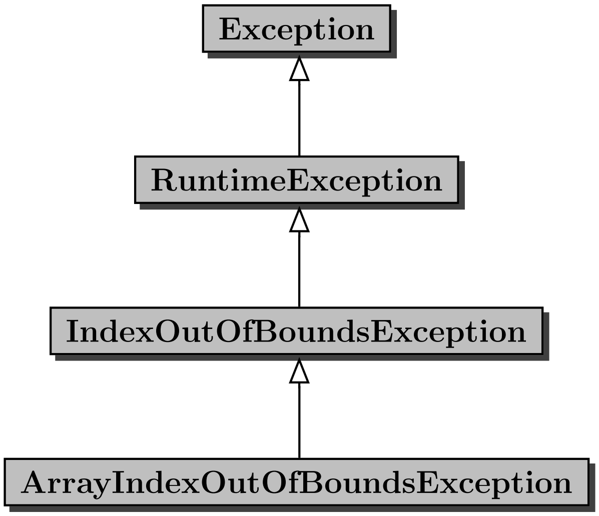
Alternative answer: In a composition, the whole cannot exist without its parts. In an aggregation, the whole and the parts can exist without each other.

Alternative answer: The aggregate A and its part P form a composition if ”A owns P”, that is, each object of type A has exclusive access to its attribute of type P.

Marking scheme: 4 marks for a correct answer.

6 (28 marks)

Consider the following UML diagram.



(a) Consider the following main method.

```
 1 public static void main(String[] args)
 2 {
 3    PrintStream output = System.out;
 4
 5    try
 6    {
 7       output.println(args[-1]);
 8       ...
 9    }
10    catch (ArrayIndexOutOfBoundsException e)
11    {
12       output.println("Invalid array index is used");
13    }
14    catch (Exception e)
15    {
16       output.println("Something went wrong!");
17    }
18 }
```

The above main method produces the following output.

```
Invalid array index is used
```

Explain what happens when the code is run. In your explanation, use the following phrases if they are relevant (not all may be relevant):

- throw(s) an exception
- terminate(s) immediately
- determine(s) the appropriate
- substitutable/substitutability

Answer:
On line 7, `args[-1]` throws an exception of type `ArrayIndexOutOfBoundsException`. Execution of the `try` block terminates immediately. The virtual machine determines that the appropriate exception handler is `catch (ArrayIndexOutOfBoundsException e)` on line 10. Program flow goes to the handler which produces the given output.

Marking scheme:

- 4 marks for correctly using "throws an exception" (or its equivalent)
- 4 marks for correctly using "terminates immediately" (or its equivalent)
- 4 marks for correctly using "determines the appropriate" (or its equivalent)

(b) Consider the following main method.

```
 1 public static void main(String[] args)
 2 {
 3    PrintStream output = System.out;
 4
 5    try
 6    {
 7       output.println(args[-1]);
 8       ...
 9    }
10    catch (IndexOutOfBoundsException e)
11    {
12       output.println("Invalid index is used");
13    }
14    catch (Exception e)
15    {
16       output.println("Something went wrong!");
17    }
18 }
```

The above main method produces the following output.

```
Invalid index is used
```

Explain what happens when the code is run. In your explanation, use the following phrases if they are relevant (not all may be relevant):

- throw(s) an exception
- terminate(s) immediately
- determine(s) the appropriate
- substitutable/substitutability

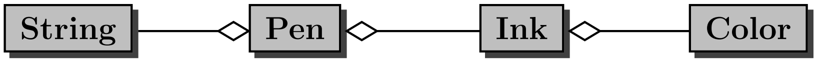
Answer:
On line 7, `args[-1]` throws an exception of type `ArrayIndexOutOfBoundsException`. Execution of the `try` block terminates immediately. The virtual machine determines that the appropriate exception handler is `catch (IndexOutOfBoundsException e)` on line 10 because `ArrayIndexOutOfBoundsException` is substitutable for `IndexOutOfBoundsException`. Program flow goes to the handler which produces the given output.

Marking scheme:

- 4 marks for correctly using "throws an exception" (or its equivalent)
- 4 marks for correctly using "terminates immediately" (or its equivalent)
- 4 marks for correctly using "determines the appropriate" (or its equivalent)
- 4 marks for correctly using "substitutable" (or its equivalent)

7 (14 marks)

Consider the following UML diagram.



Consider the following code snippet (which appears in the body of a main method).

```
1 Pen pen = new Pen("Papermate", new Ink(Color.BLUE));
2 Pen alias = ...;
3 Pen shallow = ...;
4 Pen deep = ...;
```

Assume that memory can be depicted by the diagram below when the execution reaches the end of line 1. Recall that the `String` class is immutable.

⋮	
100	`main` invocation
`pen`	600
`alias`	
`shallow`	
`deep`	
200	`Pen` class
300	`Ink` class
400	`Color` class
500	`String` class
600	`Pen` object
`name`	700
`ink`	800
700	`String` object
	`"Papermate"`
800	`Ink` object
`color`	900
900	`Color` object
⋮	

(a) Consider that an *alias* of `pen` is assigned to `alias` in line 2. Draw the diagram depicting memory when the execution reaches the end of line 2. *Draw only those blocks which have changed or are new.*

Answer:

⋮	
100	`main` invocation
`pen`	600
`alias`	600
`shallow`	
`deep`	
⋮	

Marking scheme: 2 marks if `alias` has the address 600 as its value, 0 marks otherwise.

(b) Consider that a *shallow* copy of `pen` is assigned to `shallow` in line 3. Draw the diagram depicting memory when the execution reaches the end of line 3. *Draw only those blocks which have changed or are new.*

Answer:

⋮	
100	`main` invocation
`pen`	600
`alias`	600
`shallow`	1000
`deep`	
1000	`Pen` object
`name`	700
`ink`	800
⋮	

Marking scheme:

- 2 marks if `shallow` has a new (one that was not used before) address as its value, 0 marks otherwise.
- 2 marks if there a new `Pen` object at that new address, 0 marks otherwise.
- 1 mark if the value of `name` of the new `Pen` object is 700, 0 marks otherwise.
- 1 mark if the value of `ink` of the new `Pen` object is 800, 0 marks otherwise.

(c) Consider that a *deep* copy of `pen` is assigned to `deep` in line 4. Draw the diagram depicting memory when the execution reaches the end of line 4. *Draw only those blocks which have changed or are new.*

Answer:

⋮	
100	`main` invocation
`pen`	600
`alias`	600
`shallow`	1000
`deep`	1100
1100	`Pen` object
`name`	700
`ink`	1200
1200	`Ink` object
`color`	1300
1300	`Color` object
⋮	

Marking scheme:

- 2 marks if `deep` has a new (one that was not used before) address as its value, 0 marks otherwise.
- 2 marks if there a new `Pen` object at that new address, 0 marks otherwise.
- 1 mark if the value of `name` of the new `Pen` object is 700, 0 marks otherwise. (Here you use the fact that the class `String` is immutable and, hence, there is no point to make a copy.)
- 1 mark if the value of `ink` of the new `Pen` object is the address of a new `Ink` object, 0 marks otherwise.

8 (10 marks)

(a) What is a loop invariant?

Answer: something that holds at the end of every iteration (page 193 of the textbook).

Marking scheme:

- Something like “a boolean expression (or something) that holds at the beginning (or end) of every iteration” deserves 2 marks.
- An answer that contains “boolean expression” but does that mention “every iteration” deserves 1 mark.

(b) Searching a collection for a particular element is performed using a loop. Suppose that we want to know whether or not a list contains at least one string that starts with `z`. Consider the following attempt:

```
// t is a List<String>
boolean found = false;
for (int i = 0; i < t.size(); i++)
{
   found = t.get(i).startsWith("z");
}
```

What is a useful loop invariant in the code fragment shown above?

Answer: $\texttt{found} == (\texttt{i} == 0) \lor \texttt{t.get(i - 1).startsWith("z")}$

Alternative answer: the value of `found` matches the value of “the last element visited thus far starts with a z.”

Marking scheme:

- A correct and useful loop invariant deserves 2 marks.
- If the loop invariant is incorrect but mentions the last element, then 1 mark.

(c) The loop invariant in Part (b) does not correctly solve the search problem. What is a useful loop invariant that correctly solves the search problem?

Answer: $\texttt{found} == \exists 0 \leq j < \texttt{i} : \texttt{t.get(}j\texttt{).startsWith("z")}$

Alternative answer: the value of `found` matches the value of “one of the elements visited thus far starts with a z.”

Marking scheme:

- A correct and useful loop invariant deserves 2 marks.
- If the loop invariant is incorrect but mentions that some element starts with z, then 1 mark.

(d) Using big-O notation, state the complexity of the loop shown in Part (b) where N is the number of elements in the list.

Answer: $O(N)$.

Marking scheme: 2 marks if $O(N)$, 0 marks otherwise.

(e) Suppose we want to solve a different search problem: Does a set contain all of the elements of another set? Consider the following attempt:

```
// set1 is a Set<String>
// set2 is a Set<String>
boolean containsAll = true;
for (String s1 : set1)
{
   boolean found = false;
   for (String s2 : set2)
   {
      found = found || s1.equals(s2);
   }
   containsAll = containsAll && found;
}
```

Using big-O notation, state the complexity of the code fragment shown above. Explain your answer (but do not formally prove your answer). You can assume that both sets always have N elements.

Answer: $O(N^2)$.

Marking scheme: 2 marks if $O(N^2)$, 0 marks otherwise.