Testing on Steroids (continued)

EECS 4315

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Correctness of the JUnit test cases

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Answer

Should we test the tests that test the JUnit test cases?

We may find bugs in our tests when a test case fails and we inspect our code and the test case. When evaluating test cases, we are often interested in coverage (code, path).

Test the Color class

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Answer

No.

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Answer

No.

Question

Why not?

Test the Color class

Question

If we run the JUnit test case `ColorTest` and all tests pass, can we conclude that the class `Color` correctly implements the API?

Answer

No.

Question

Why not?

Answer

Run the JUnit test case `ColorTest` several times.

Test the Color class

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How is it possible that the JUnit test case `ColorTest` passes all tests pass in some runs and fails the method `testConstructorAndAccessors` in other runs?

Test the Color class

Question

How is it possible that the JUnit test case `ColorTest` passes all tests pass in some runs and fails the method `testConstructorAndAccessors` in other runs?

Answer

Let's have a look at the code of `getBlue`.

Test the Color class

Question

How is it possible that the JUnit test case `ColorTest` passes all tests pass in some runs and fails the method `testConstructorAndAccessors` in other runs?

Answer

Let's have a look at the code of `getBlue`.

Answer

Because the code of `getBlue` uses randomization.

Randomization

Question

Why are we interested in randomization in our code?

Randomization

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Why are we interested in randomization in our code?

Answer

The source code of most computer and video games contains some sort of randomization. This provides games with the ability to surprise players, which is a key factor to their long-term appeal.

Katie Salen and Eric Zimmerman. *Rules of Play: Game Design Fundamentals*. The MIT Press. 2004.

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Answer

Randomized algorithms such as stochastic gradient descent have become important optimization methods in machine learning.

Tong Zhang. Solving large scale linear prediction problems using stochastic gradient descent algorithms. In, Carla Brodley, editor, *Proceedings of the 21st International Conference on Machine Learning*, Banff, AB, Canada, July 2004. ACM

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Answer

- Randomized quicksort.
- Skiplist.
- ...

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Question

Which algorithms exploit randomization this way?

Answer

- Consensus problem (in an asynchronous distributed system in which processes may fail).
- ...

Nondeterminism

Nondeterministic code is code that, even for the same input, can exhibit different behaviors on different runs, as opposed to deterministic code.

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Besides randomization, are there other programming concept that give rise to nondeterminism?

Nondeterminism

Nondeterministic code is code that, even for the same input, can exhibit different behaviors on different runs, as opposed to deterministic code.

Randomization gives rise to nondeterminism.

Question

Besides randomization, are there other programming concept that give rise to nondeterminism?

Answer

Concurrency.

Space Exploration

EECS 4315

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Testing nondeterministic code

```
public class RandomFraction {
  public static void run() {
    Random random = new Random(System.currentTimeMillis());
    System.out.print(1 / random.nextInt(1000000));
  }
}
```

Question

If we run the above app 1,000,000 times, what is the probability that it does not throw an exception in any of those runs?

Testing nondeterministic code

Answer

- The probability of choosing zero is

Testing nondeterministic code

Answer

- The probability of choosing zero is $\frac{1}{1{,}000{,}000}$.
- The probability of not choosing zero is

Testing nondeterministic code

Answer

- The probability of choosing zero is $\frac{1}{1{,}000{,}000}$.
- The probability of not choosing zero is $1 - \frac{1}{1{,}000{,}000} = \frac{999{,}999}{1{,}000{,}000}$.
- The probability of not choosing zero one million times in a row is

Testing nondeterministic code

Answer

- The probability of choosing zero is $\frac{1}{1{,}000{,}000}$.
- The probability of not choosing zero is $1 - \frac{1}{1{,}000{,}000} = \frac{999{,}999}{1{,}000{,}000}$.
- The probability of not choosing zero one million times in a row is $(\frac{999{,}999}{1{,}000{,}000})^{1{,}000{,}000} \approx 0.37$.

Limitations of testing

Limitations of testing of nondeterministic code include

- no guarantee that all different behaviours have been checked, and
- errors may be difficult to reproduce.

Alternatives to testing

To detect bugs in nondeterministic code, testing needs to be supplemented with other approaches.

Question

How to tackle the limitations of testing of nondeterministic code?

Alternatives to testing

To detect bugs in nondeterministic code, testing needs to be supplemented with other approaches.

Question

How to tackle the limitations of testing of nondeterministic code?

Answer

Control the nondeterminism: this allows us to

- systematically check all different behaviours and
- reproduce errors.

Exercises

Solve the following exercises. Fill in the body of the following main method.

```
public class Exercise {
  public static void main(String[] args) {
    Random random = new Random();
  }
}
```

using only the `nextBoolean` method of the `Random` class.

Exercises

1. The app prints either 1 or 2, both with probability 0.5.
2. The app prints 1, 2, 3, or 4, each with probability 0.25.
3. The app prints any integer, each with positive but not necessarily equal probability.

Executions

- The first app has two different executions.
- The second app has four different executions

Question

How many different executions has the third application?

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Question

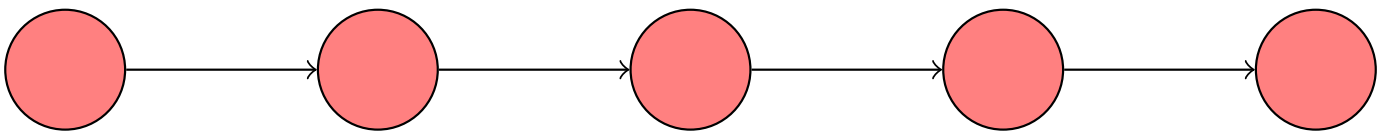
How many different executions has the third application?

Answer

Infinitely many or $2^{32} = 4,294,967,296$ (depending on how implemented).

Execution

An execution consists of states connected by transitions.



State

A state of a Java virtual machine (JVM) includes

- the heap,
- for each thread
  - its state (runnable, waiting, terminated, ...),
  - its stack,
  - etc,
- etc.

docs.oracle.com/javase/8/docs/platform/jvmti/jvmti.html

Transition

A transition of a JVM takes the JVM from one state to another by executing a bytecode instruction.

Java code

```
public class HelloWorld {
  public static void main(String[] args) {
    System.out.println("Hello World");
  }
}
```

Java bytecode

The command

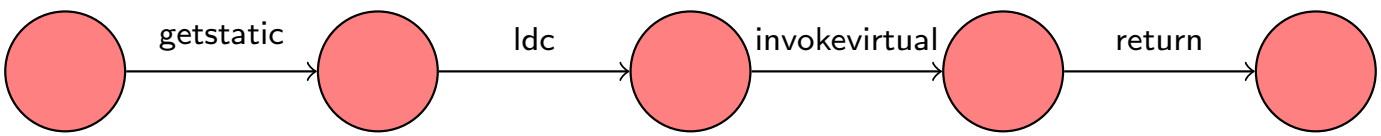
```
javap -c HelloWorld.class
```

produces

```
0: getstatic
// of attribute System.out of class PrintStream
3: ldc
// String "Hello World"
5: invokevirtual
// of method println with argument String
8: return
```

Java code and execution

```
public class HelloWorld {
  public static void main(String[] args) {
    System.out.println("Hello World");
  }
}
```



Java code

```
public class RedOrGreen {
  public static void main(String[] args) {
    Random random = new Random();
    if (random.nextBoolean()) {
      System.out.println("Red");
    } else {
      System.out.println("Green");
    }
  }
}
```

Java bytecode

```
0: new
3: dup
4: invokespecial
7: astore_1
8: aload_1
9: invokevirtual
12: ifeq
15: getstatic
18: ldc
20: invokevirtual
23: goto
26: getstatic
29: ldc
31: invokevirtual
34: return
```

Executions

Question

Draw the state-transition diagram.

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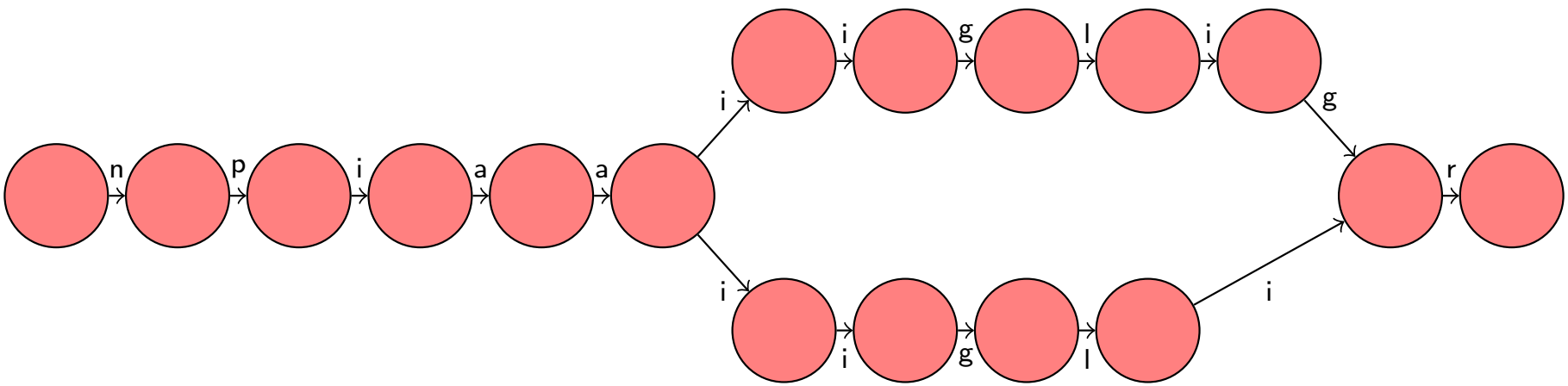


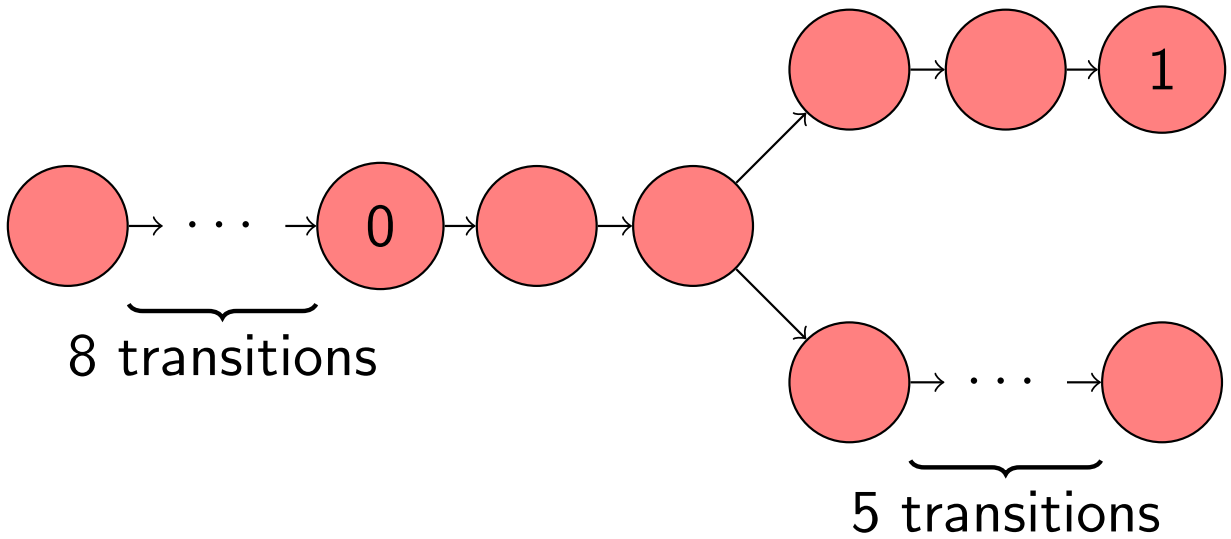
Executions

Question

Draw the state-transition diagram corresponding to

```
Random random = new Random();
int value = 0;
while (random.nextBoolean()) {
  value++;
}
System.out.println(value);
```

Executions



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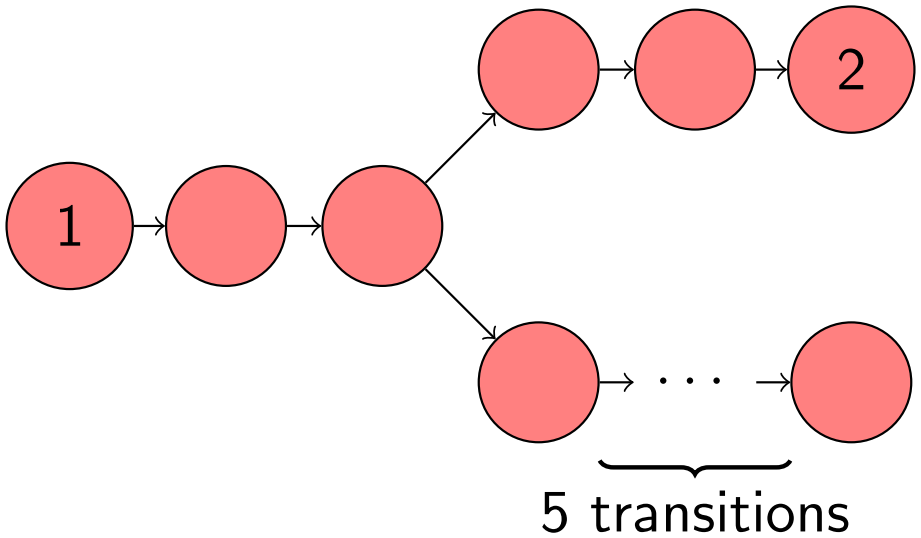

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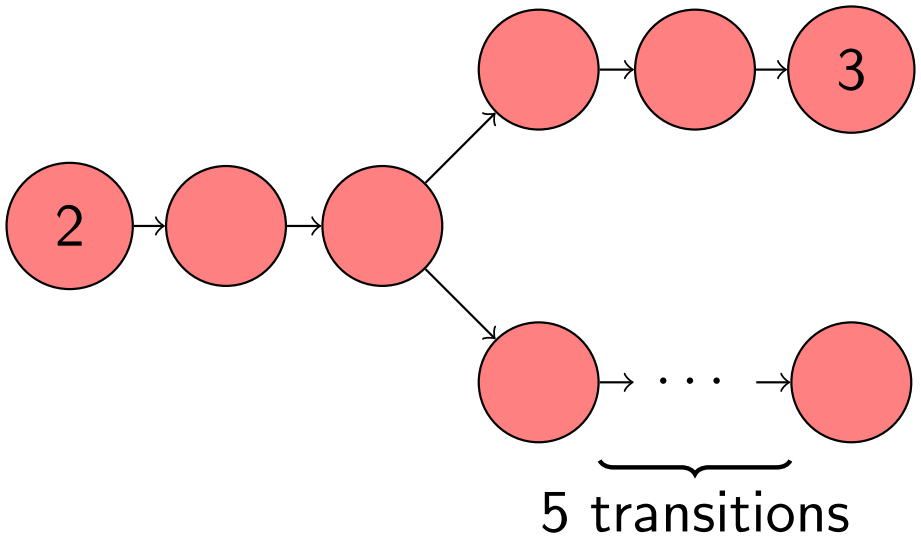

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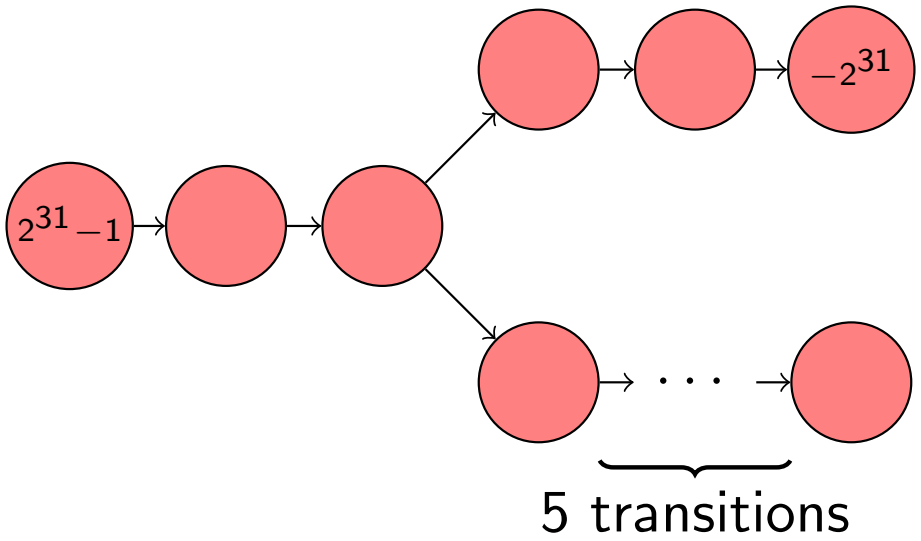

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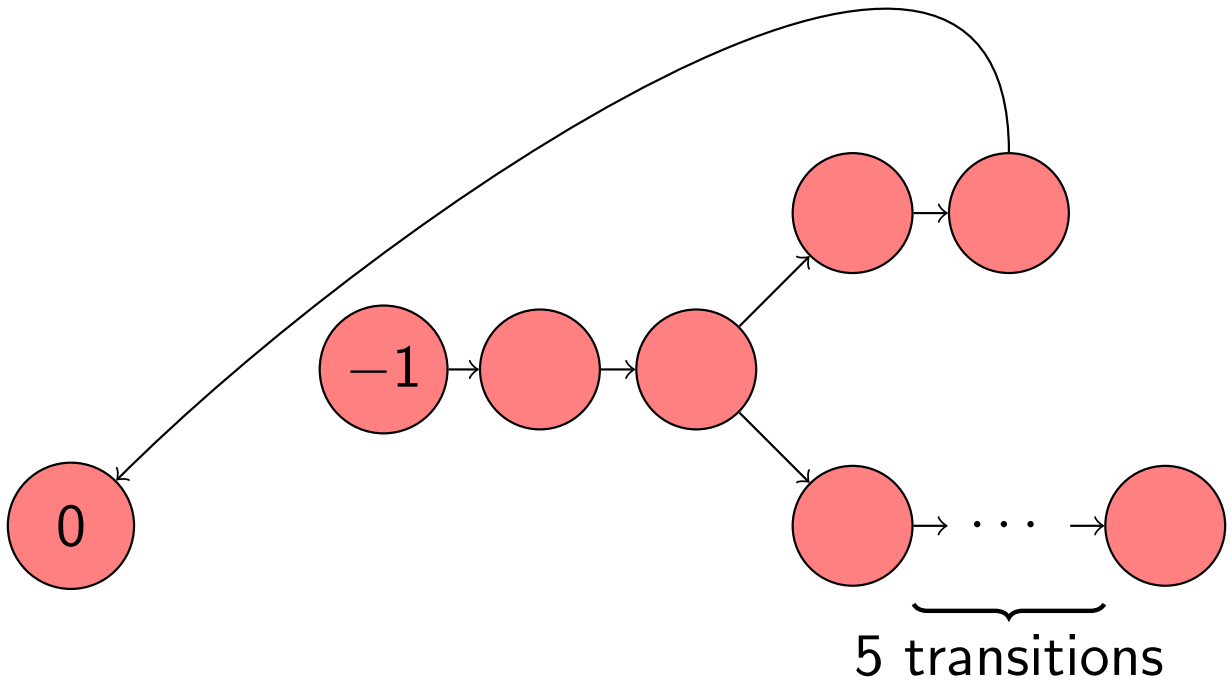

The state space explosion problem

Problem

The size of the state space, that is, the number of states, may become very large.

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The size of the state space, that is, the number of states, may become very large.

This is one of the major challenges in model checking.