Probabilistic Model Checking of Randomized Java Code

Syyeda Zainab Fatmi, Xiang Chen, Yash Dhamija, Maeve Wildes, Qiyi Tang, and Franck van Breugel

July 12, 2021

Motivation

The Miller-Rabin primality test determines whether a number given as input is prime. The algorithm may erroneously report that the input number is prime.

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Monte Carlo algorithms are randomized algorithms that may produce incorrect results with a small probability.

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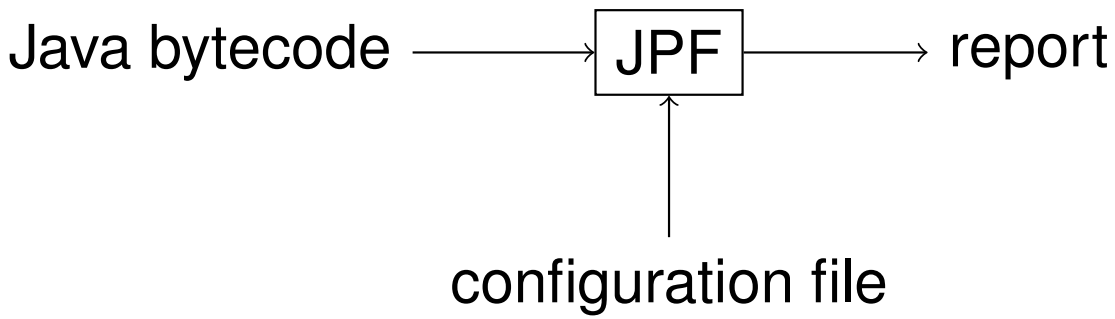
Java PathFinder (JPF) is the most popular model checker for Java code.



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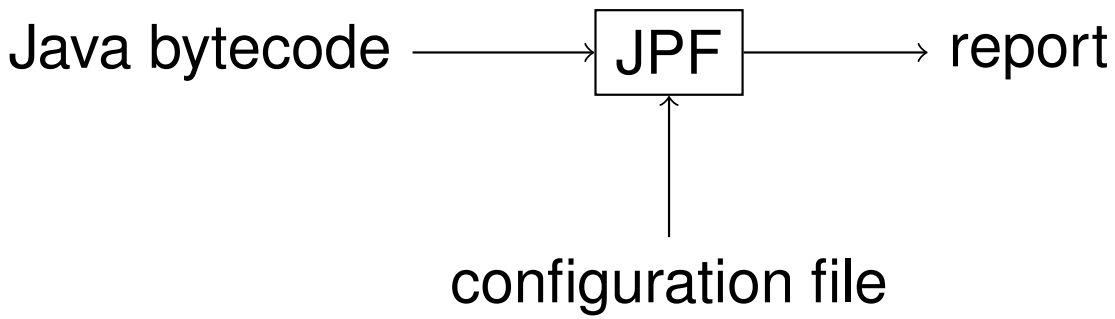
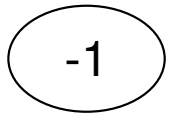


However, JPF cannot handle probabilistic properties.



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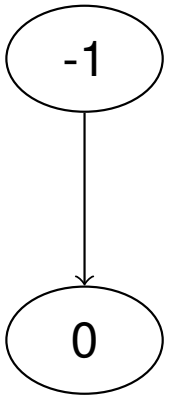

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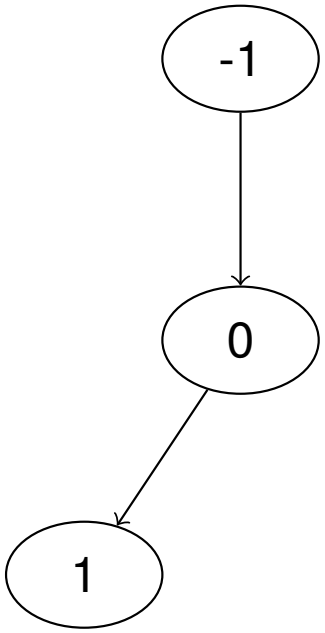

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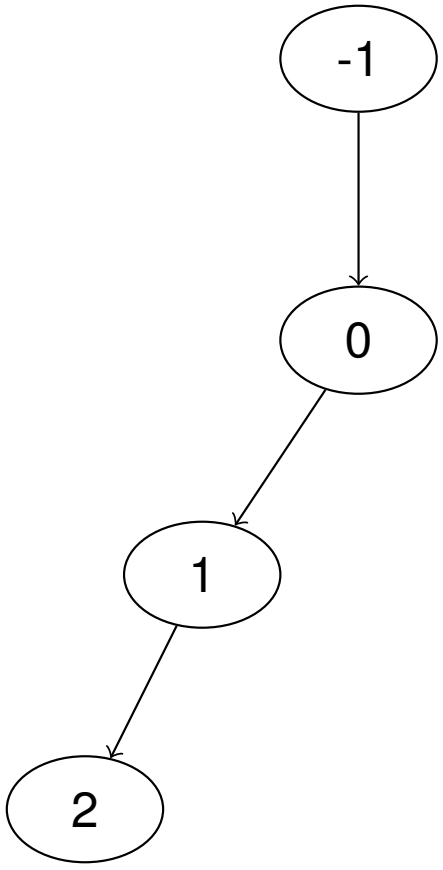

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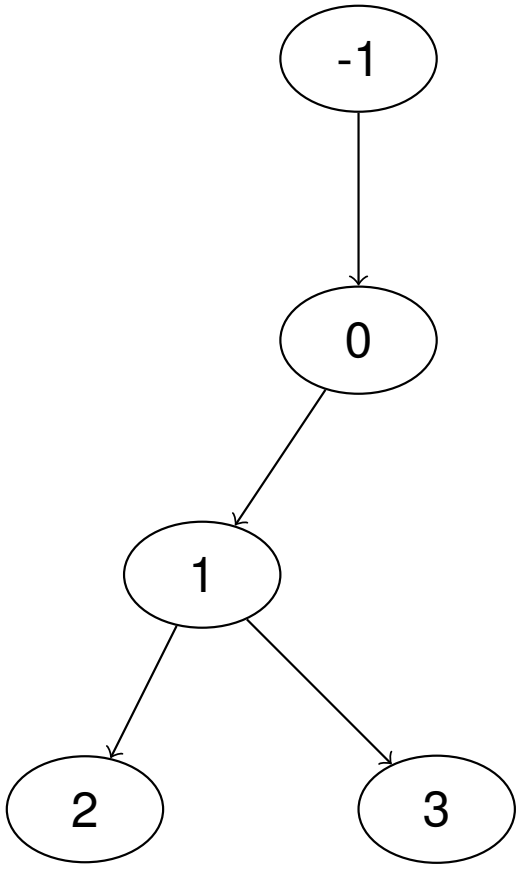

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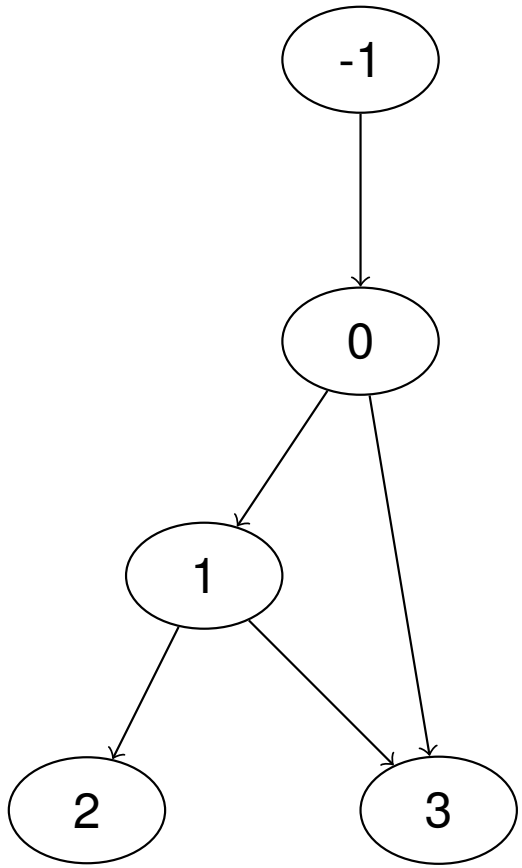
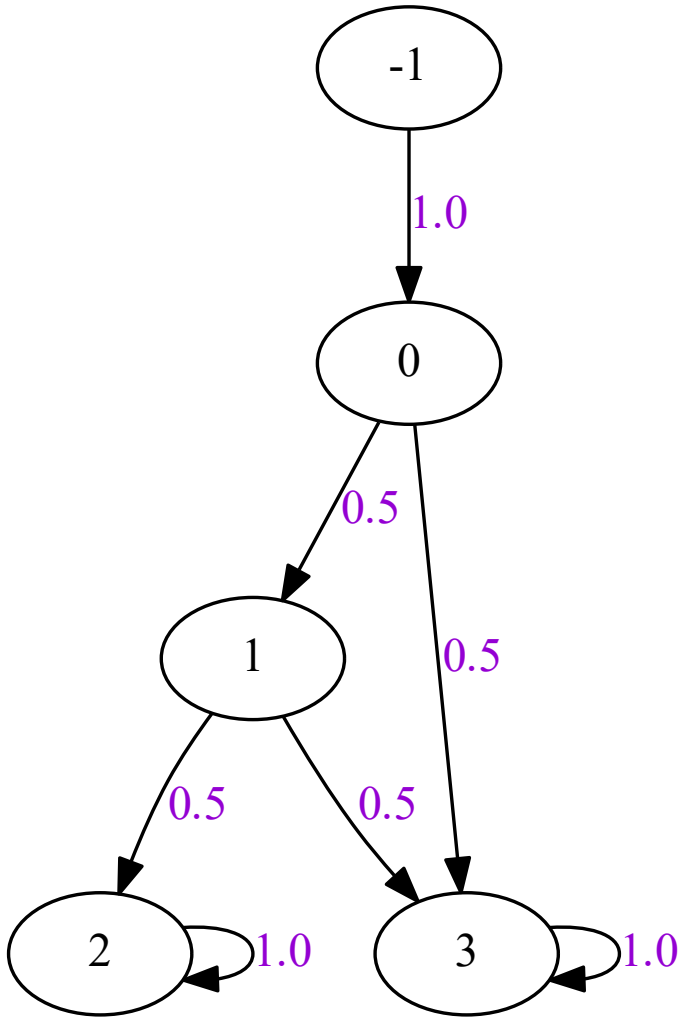


jpf-probabilistic

jpf-probabilistic assigns probabilities to the transitions of the model, which reflect the random choices in the Java code.



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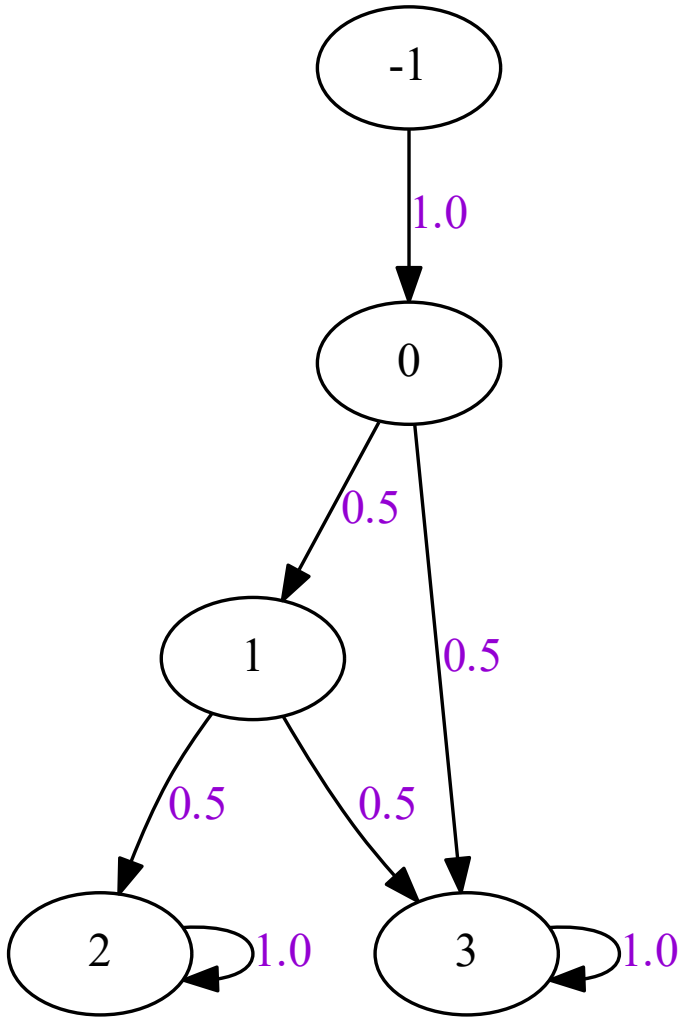
This turns the state space into a discrete-time Markov chain (DTMC).



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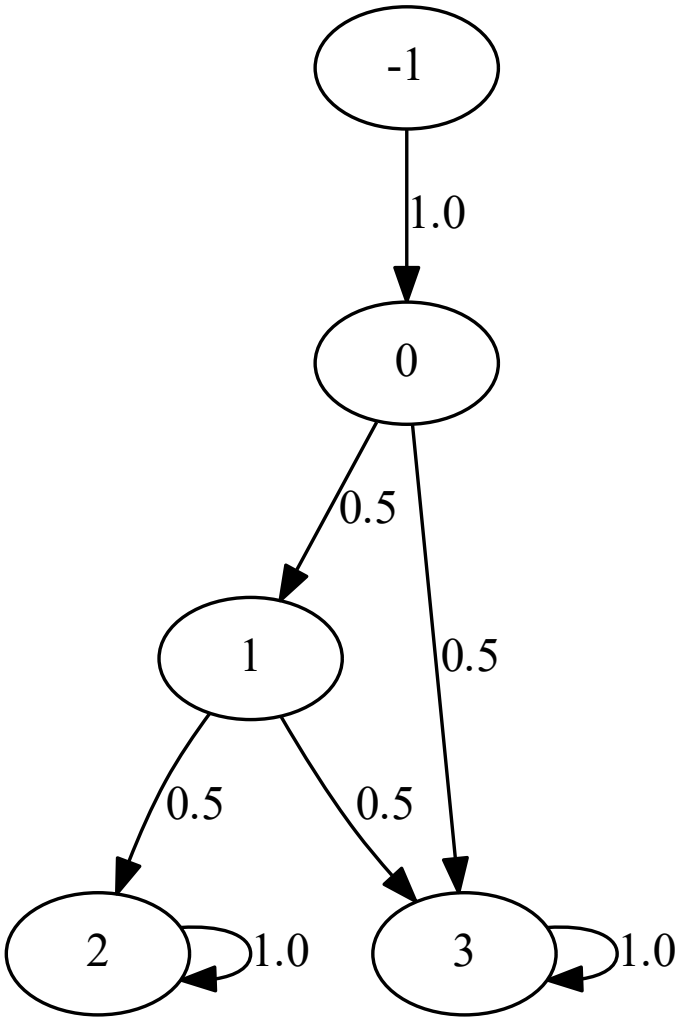


```
1  5 7
2  -1 0 1.0
3  0 1 0.5
4  1 2 0.5
5  2 2 1.0
6  1 3 0.5
7  3 3 1.0
8  0 3 0.5
```

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To traverse the state space, JPF supports

- depth-first search (DFS) and
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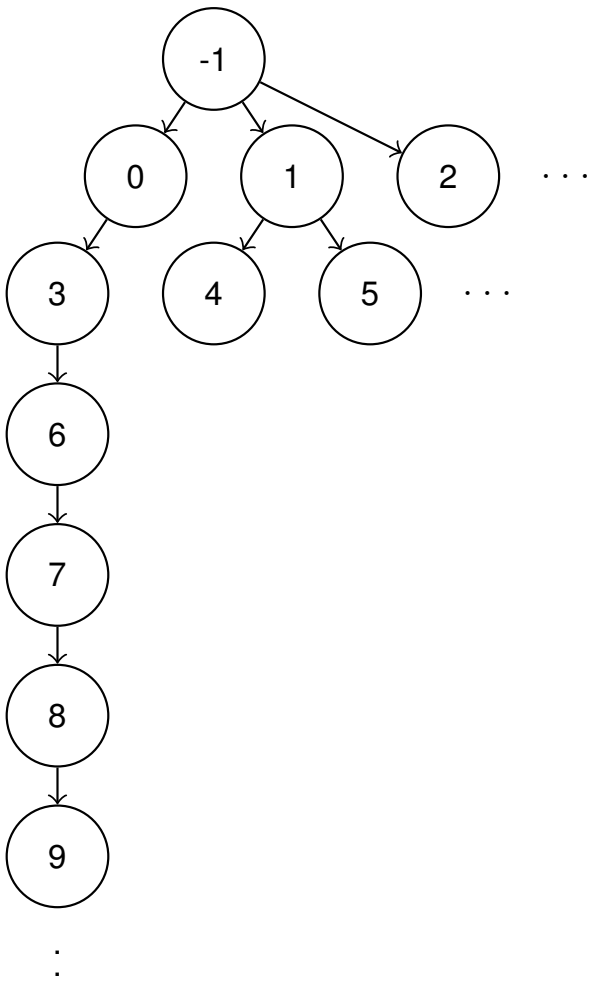

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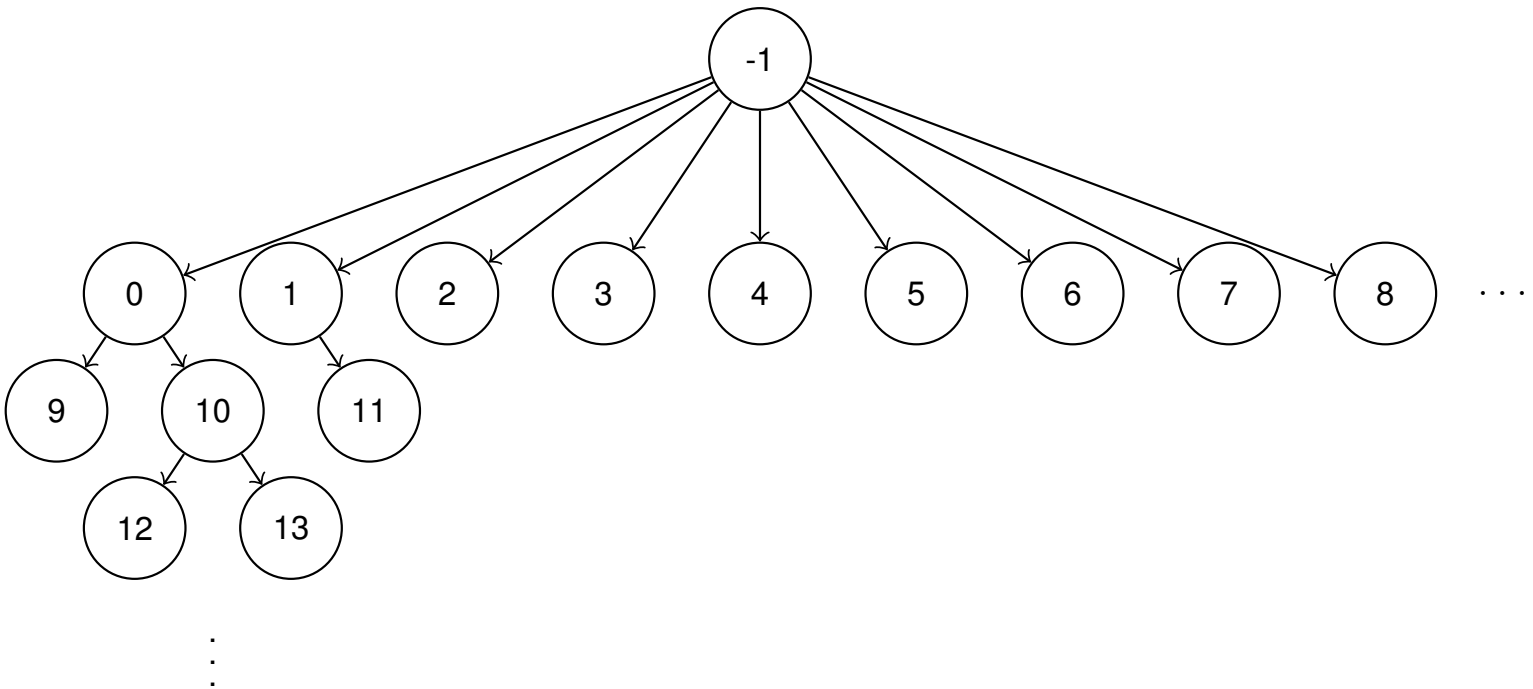

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To traverse the state space, JPF supports

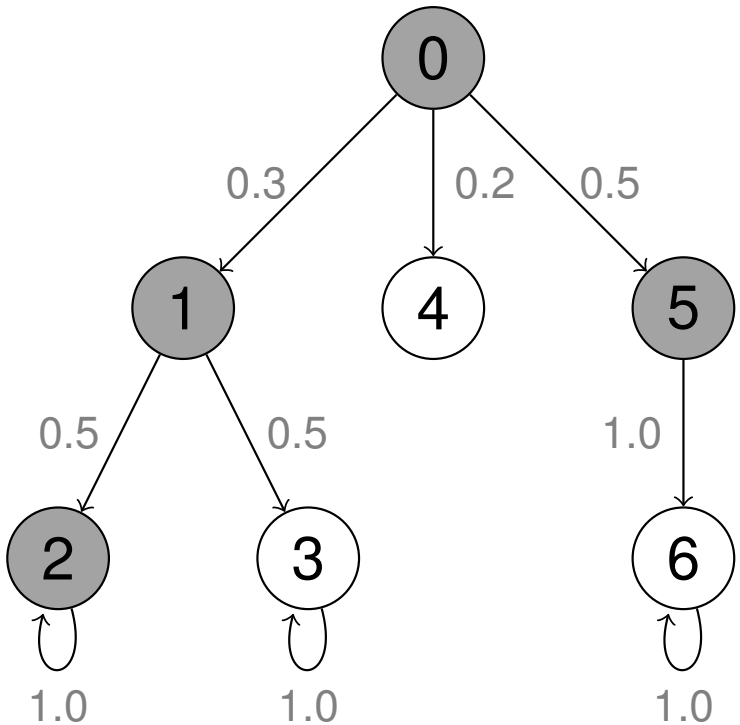
- depth-first search (DFS) and
- breadth-first search (BFS).

jpf-probabilistic provides

- probability-first search (PFS),
- random search (RS),
- softmax search (SMS), and
- ϵ-greedy search (EGS).

jpf-probabilistic

1. PFS
   always chooses a state whose path along which it is discovered has the highest probability.



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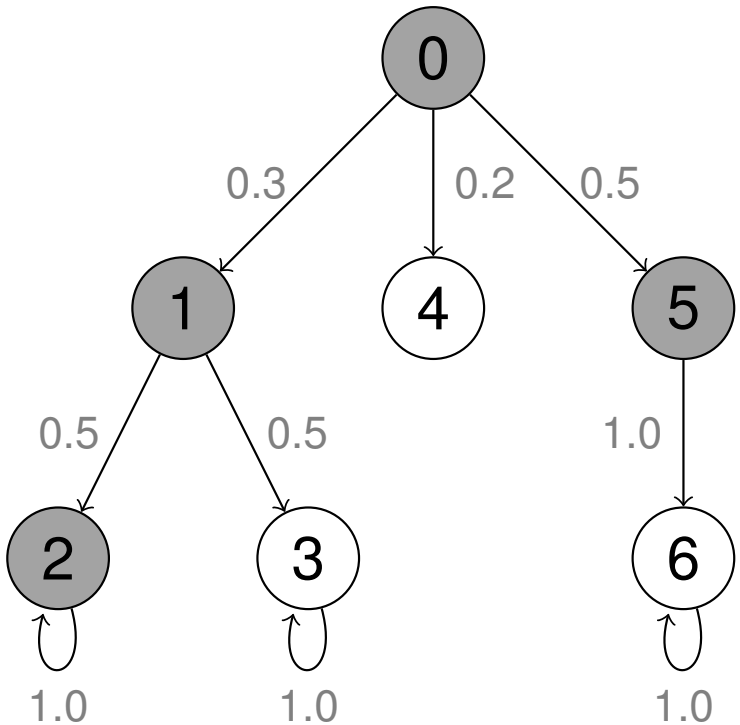

$$p(s_3) = 0.15$$
$$p(s_4) = 0.2$$
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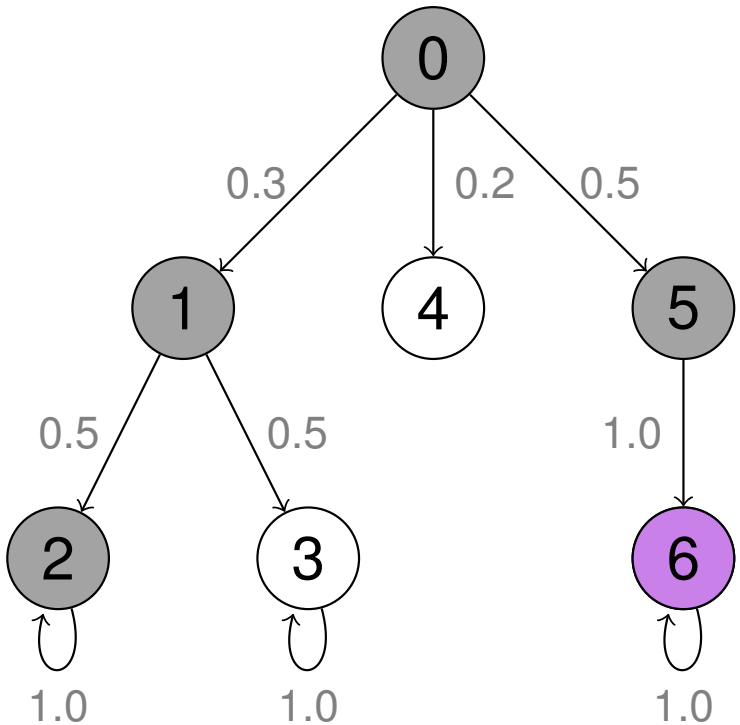

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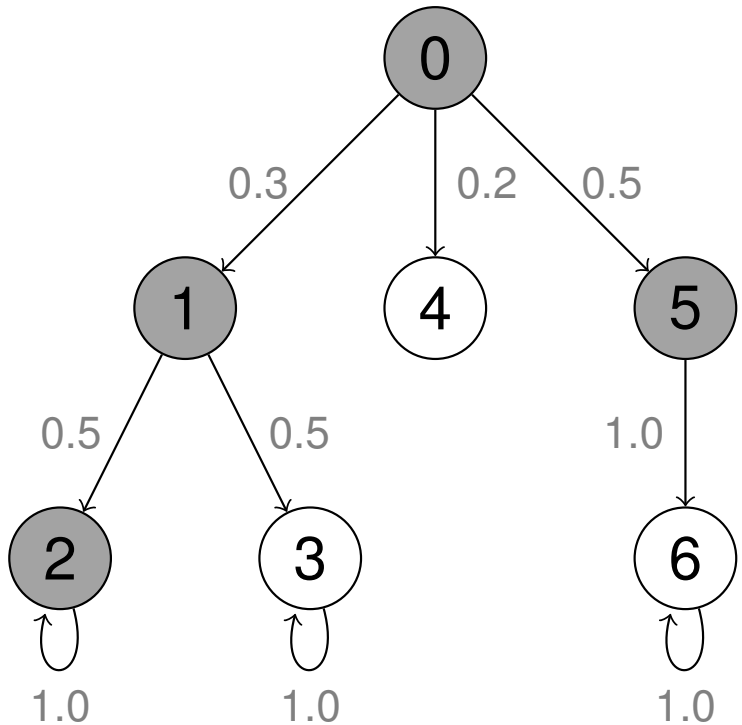
2. RS
   chooses state s_j with probability

$$\frac{p(s_j)}{\sum_{0 \le i \le n} p(s_i)}.$$



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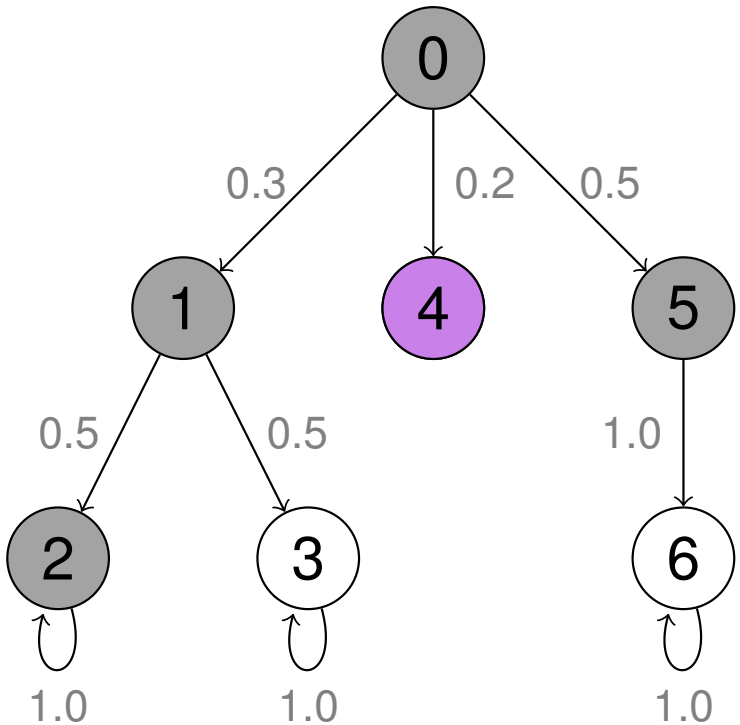

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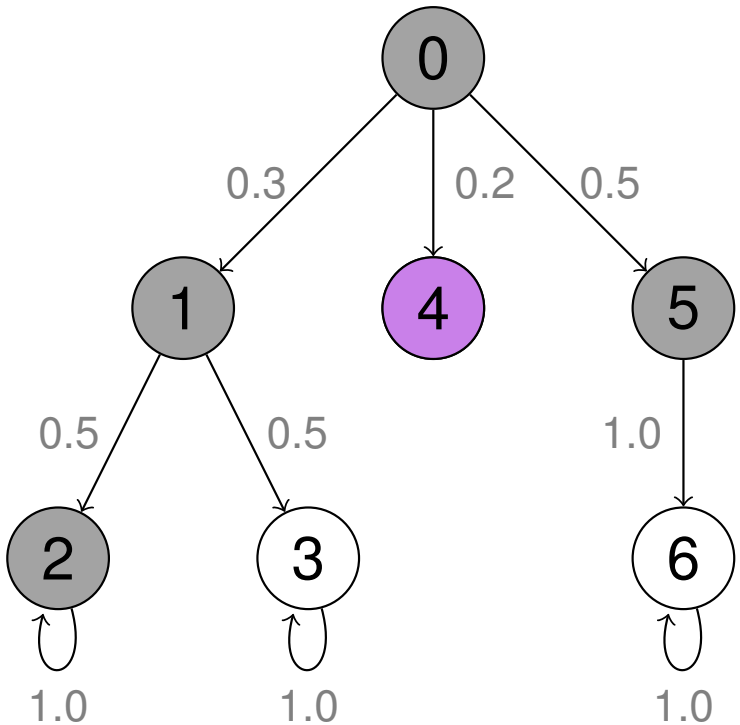

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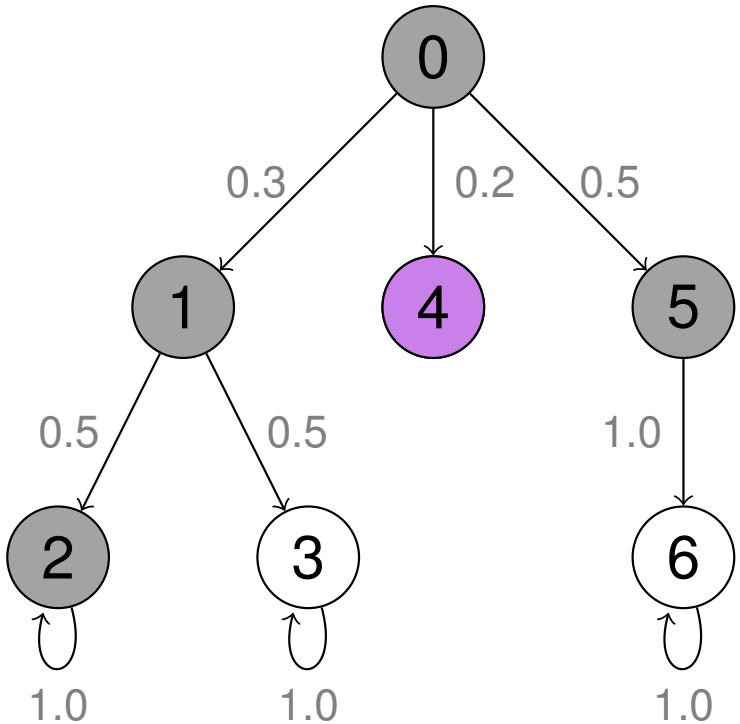

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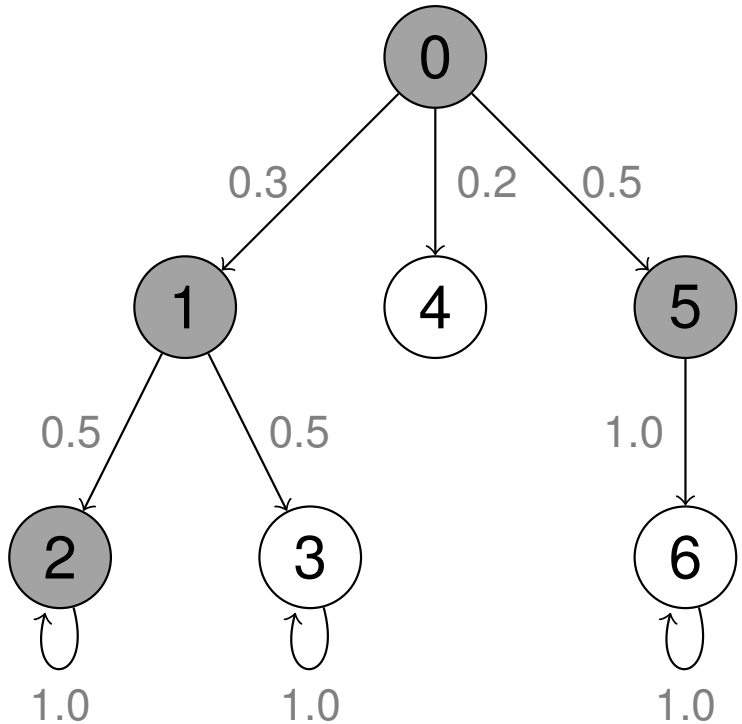
$$\frac{e^{p(s_j)/\tau}}{\sum_{0 \le i \le n} e^{p(s_i)/\tau}},$$

   where τ is the temperature.



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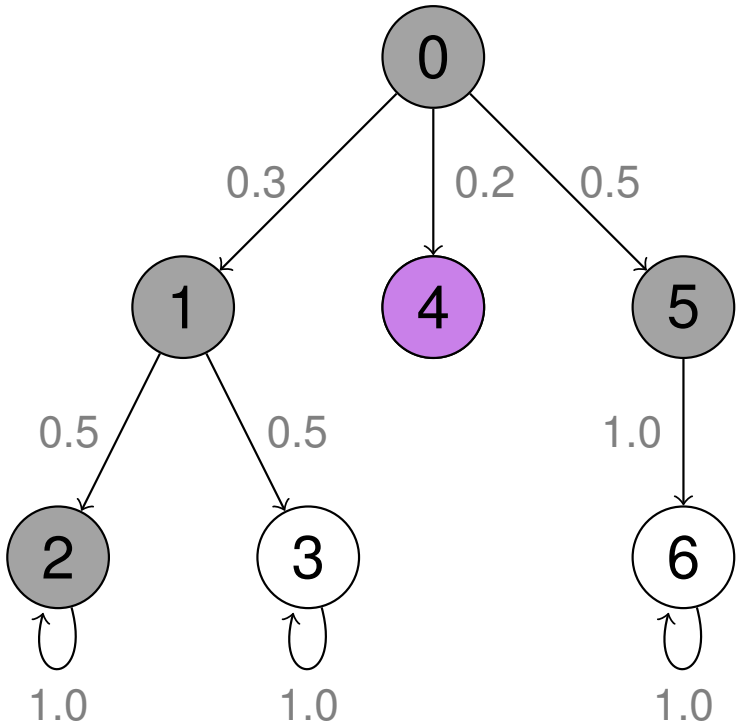

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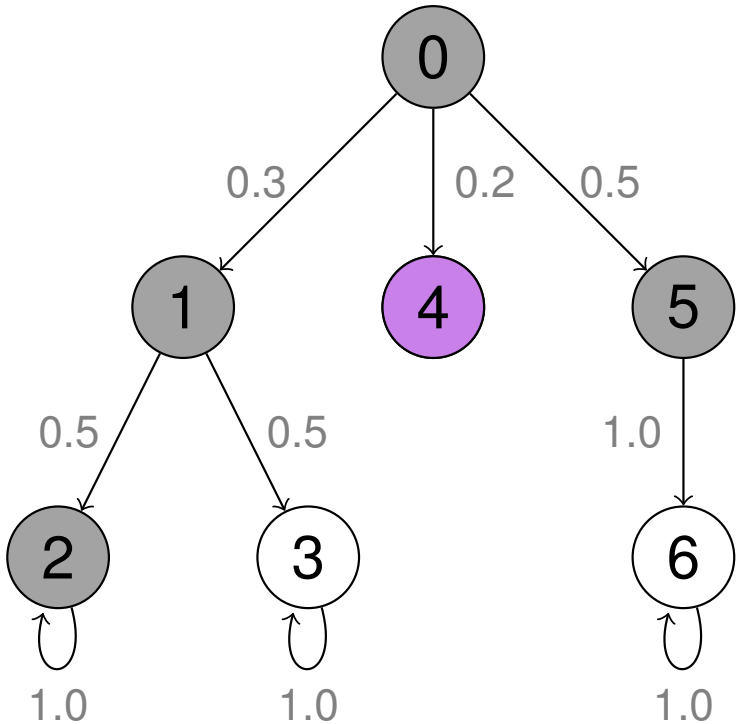

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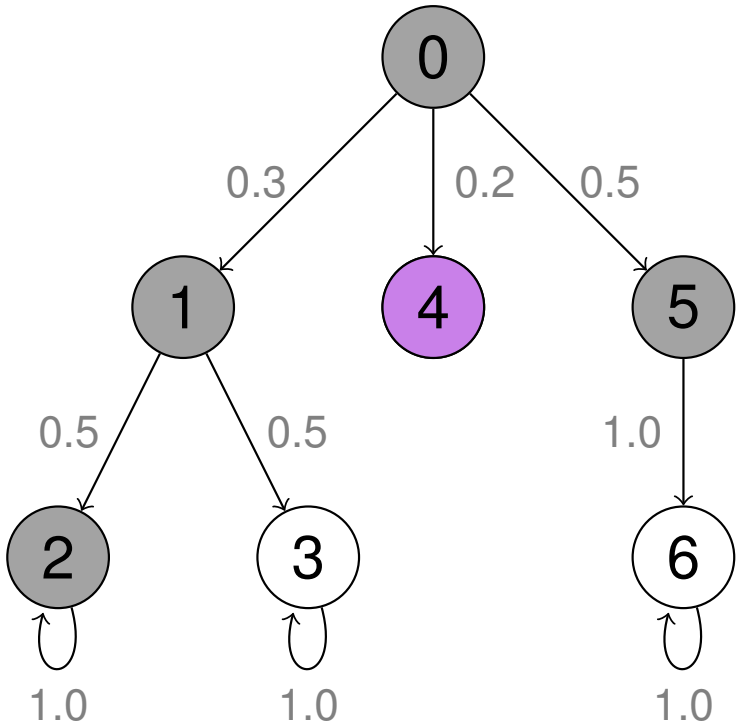
   assume $\tau = 2$, chooses s_4 with probability 0.319



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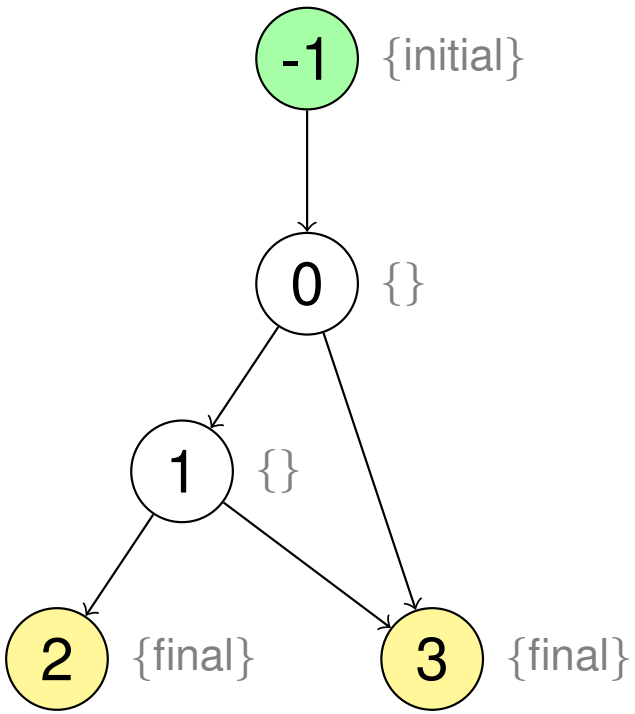
4. EGS
   behaves like PFS with probability $1 - \epsilon$ and behaves like RS and with probability ϵ.

jpf-label

To capture simple known facts about the modelled software, the states are usually labelled with a set of atomic propositions.



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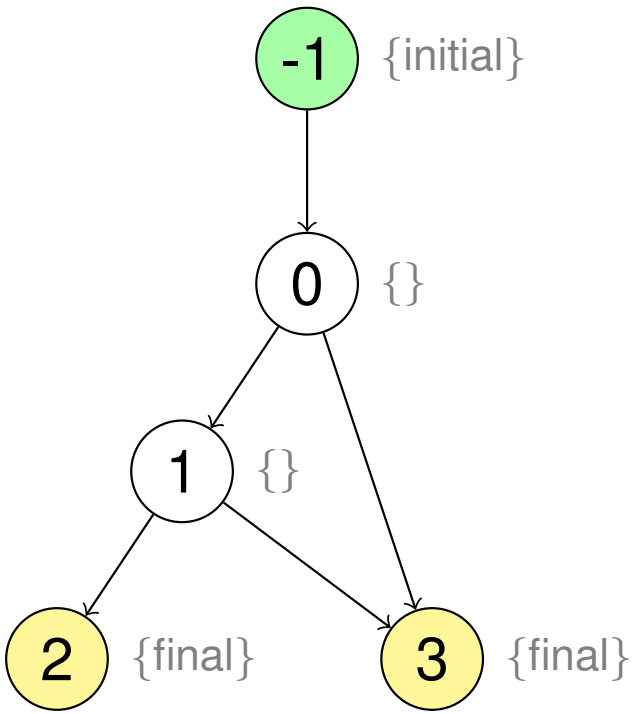
These atomic propositions may be used to express properties of the code.



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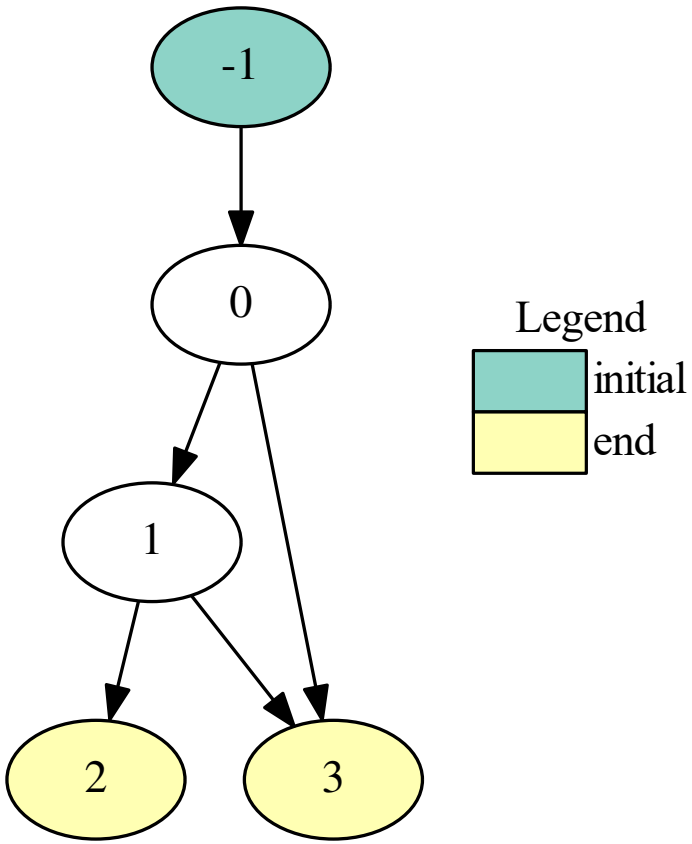



```
1  0="init" 1="end"
2  -1: 0
3  2: 1
4  3: 1
```

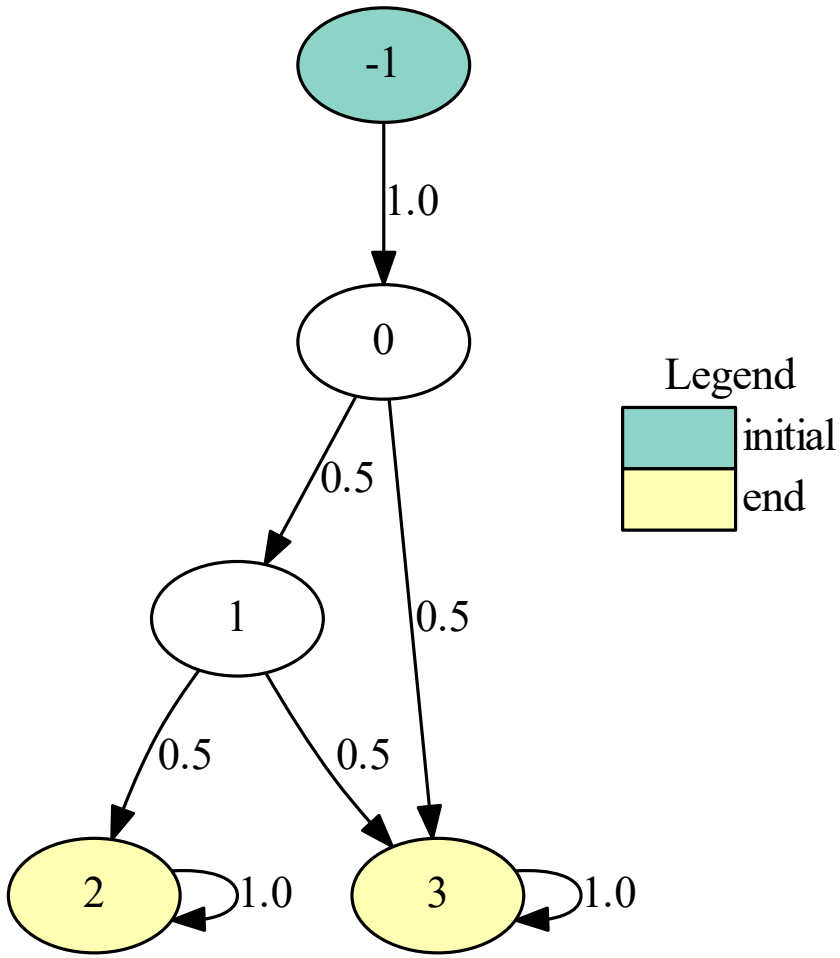
jpf-label

We provide twelve different ways to label states, including:

- initial and final states,
- boolean and integer static fields,
- boolean and integer local variables,
- method invocations,
- method returns and the values returned, and
- thrown exceptions and the exception types.

Our extensions

JPF, extended with jpf-probabilistic and jpf-label, can construct a labelled Markov chain that models the given Java code.



PRISM

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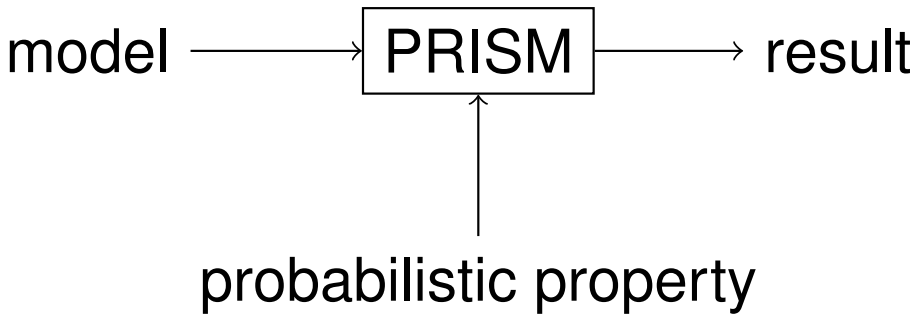

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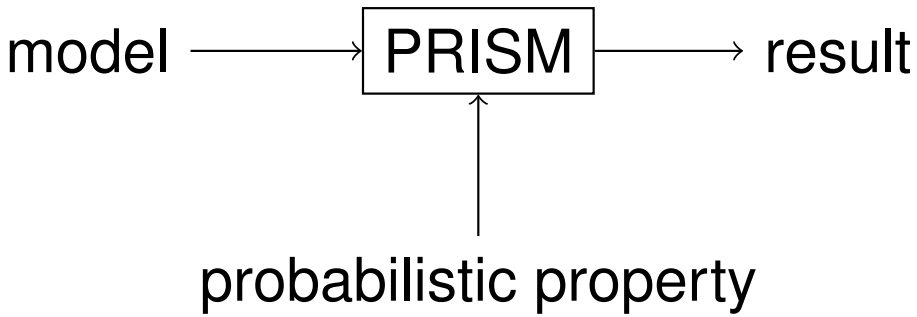
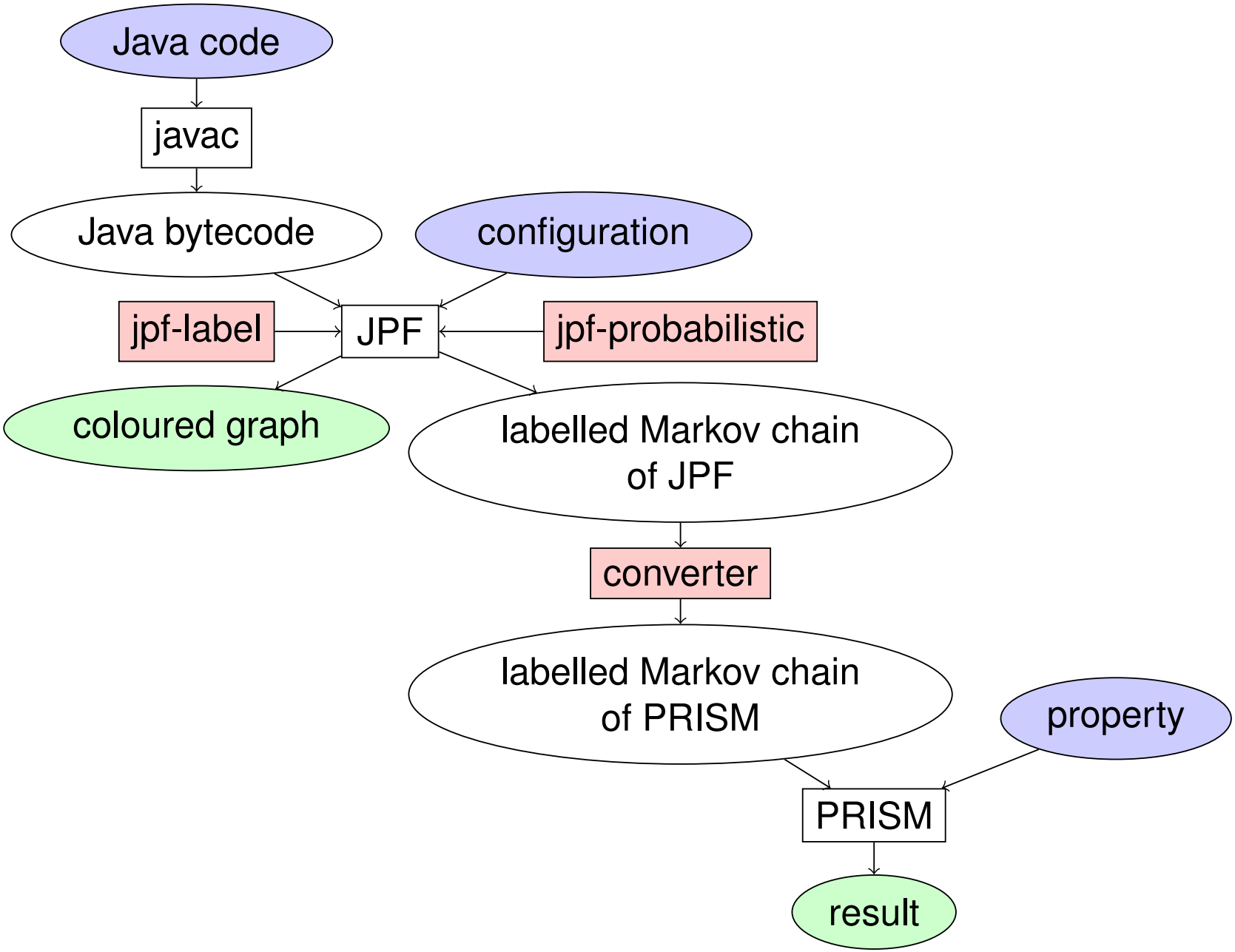


However, some algorithms cannot be easily translated into PRISM's input language.

Our tool


Java code
javac
Java bytecode
configuration
jpf-label
JPF
jpf-probabilistic
coloured graph
labelled Markov chain
of JPF
converter
labelled Markov chain
of PRISM
property
PRISM
result

Miller-Rabin Primality Test

Let us revisit our example and apply our tool to the problem.

Conclusion

Our extensions of JPF, jpf-label and jpf-probabilistic,

- provide an easy way to the label the states
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- assign probabilities to the transitions
- introduces new search strategies

Our tool

- builds a bridge between the model checkers JPF and PRISM
- is accompanied by numerous realistic randomized algorithms

Thank You

Our tool can be found on GitHub at:

github.com/javapathfinder/jpf-label
github.com/javapathfinder/jpf-probabilistic