# PyModel
# Model-based testing in Python

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# Model-based testing

**Unit testing**: code each test case, including an assertion that checks whether the test passed

**Model-based testing**: code a *model* that generates as many test cases as desired, and also acts as the oracle that checks whether any case passed

A model-based testing project is a programming project!

In PyModel the models are coded in Python. It is convenient when the implementation under test is also in Python (but this is not required).

# Model-based testing

What problem does model-based testing solve?

Testing *behavior*: ongoing activities that may exhibit history-dependence and nondeterminism.

Many variations (data values, interleavings, etc.) should be tested for each scenario (or use case).

So many test cases are needed that it is not feasible to code them all by hand.

Examples: communication protocols, web applications, control systems, user interfaces, ...

# Behavior

We need to test *behavior*: ongoing activities that may exhibit history dependence and nondeterminism.

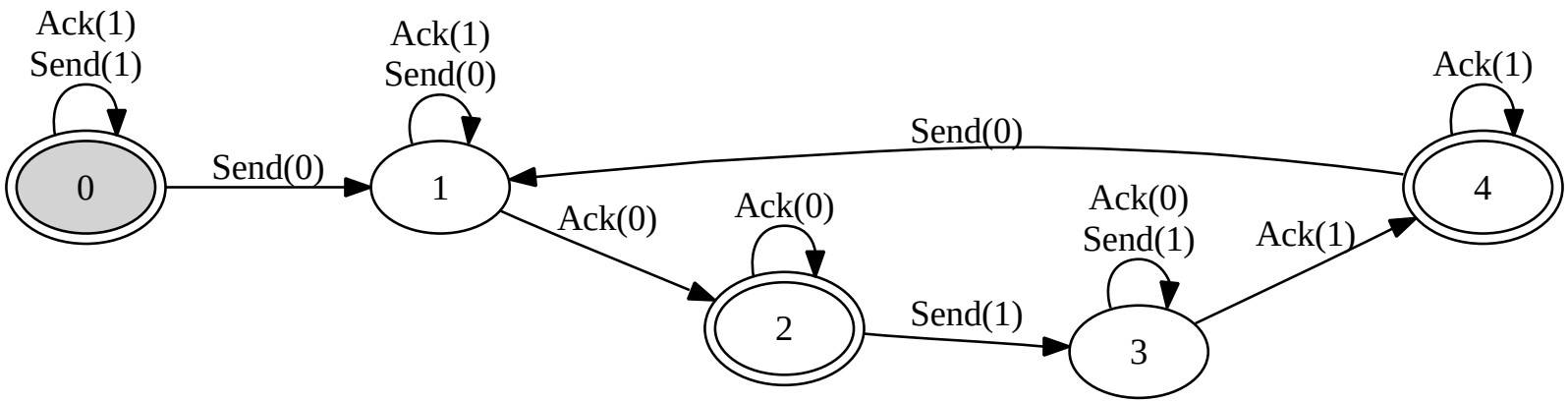
We represent behavior with *traces*: sequences of *actions* with arguments. Specify a system by describing which traces are allowed, and which are forbidden.

Example: alternating bit protocol

| Allowed | Allowed | Allowed | Allowed | Forbidden | Forbidden |
|---|---|---|---|---|---|
| Send(0) | Send(1) | Send(1) | Send(1) | Send(0) | Send(0) |
| Ack(0) | Send(1) | Send(1) | Ack(1) | Ack(0) | Ack(1) |
| Send(1) | Ack(1) | Ack(1) | Send(1) | Send(0) | Send(1) |
| Ack(1) | Send(0) | Send(1) | Ack(1) | Ack(0) | Ack(1) |
| | Ack(1) | Ack(1) | Ack(1) | | |
| | Ack(1) | Send(1) | Send(0) | | |
| | Send(0) | | Ack(0) | | |
| | Ack(0) | | | | |

# Finite State Machines

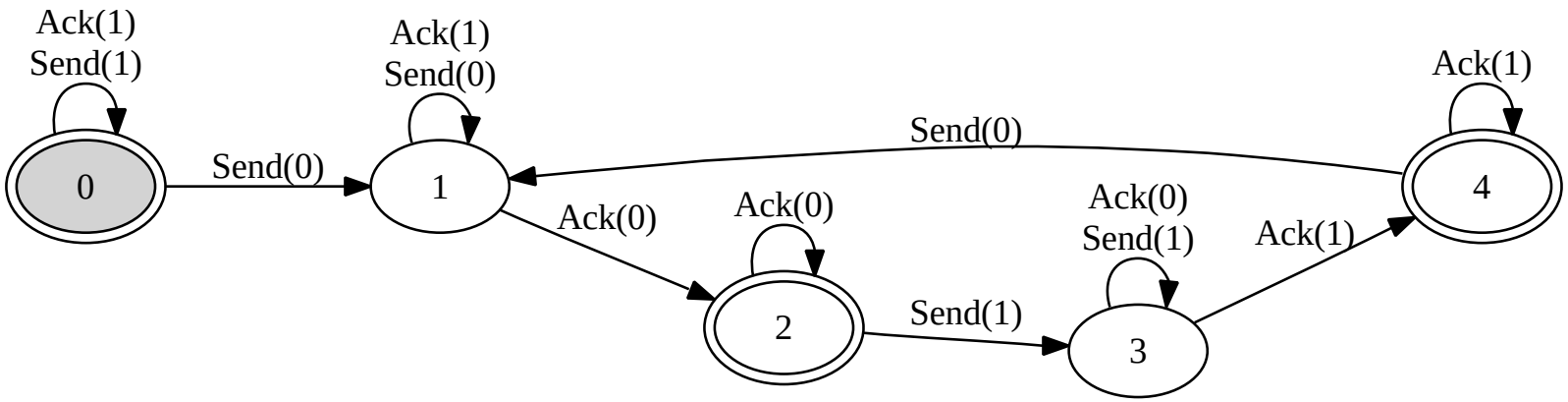
Finite State Machines (FSMs) can represent finite behaviors. Every path through the graph represents an allowed trace.




| Allowed | Allowed | Allowed | Allowed | Forbidden | Forbidden |
|---|---|---|---|---|---|
| Send(0) | Send(1) | Send(1) | Send(1) | Send(0) | Send(0) |
| Ack(0) | Send(1) | Send(1) | Ack(1) | Ack(0) | Ack(1) |
| Send(1) | Ack(1) | Ack(1) | Send(1) | Send(0) | Send(1) |
| Ack(1) | Send(0) | Send(1) | Ack(1) | Ack(0) | Ack(1) |
| | Ack(1) | Ack(1) | Ack(1) | | |
| | Ack(1) | Send(1) | Send(0) | | |
| | Send(0) | | Ack(0) | | |
| | Ack(0) | | | | |

# Finite State Machines

FSMs are one kind of model in PyModel, coded as follows:




```
graph = ((0, (Send, (1,), None), 0),
         (0, (Ack, (1,), None), 0),
         (0, (Send, (0,), None), 1),
         (1, (Ack, (0,), None), 2),
         ... etc. ...
         (4, (Send, (0,), None), 1))
```

The PyModel Graphics program **pmg** generates graphics from an FSM in this form.

# Generating tests

The PyModel Tester **pmt** generates traces from a model. Each trace describes a test run, including the expected test results.

**Offline testing**: pmt saves the traces in a test suite.

**On-the-fly testing**: pmt executes the traces as they are generated.

```
C:\Users\jon\Documents\mbt\samples\abp>pmt.py -n 10 ABP
Send(1,)
Send(1,)
Ack(1,)
Send(1,)
Ack(1,)
Send(0,)
Ack(1,)
Send(0,)
Ack(0,)
Ack(0,)
Finished at step 10, reached accepting state
```

# Model programs

*Model programs* are another kind of model in PyModel. They can describe behaviors where the action arguments can have an "infinite" (very large) number of values.

A model program consists of *state variables*, *action functions* and *enabling conditions*.

```
stack = list()          # State

def Push(x):            # Push is always enabled
  global stack
  stack.insert(0,x)

def Pop():              # Pop requires an enabling condition
  global stack
  result = stack[0]
  del stack[0]
  return result

def PopEnabled():       # Pop is enabled when the stack is not empty
  return stack
```

# Exploration

The PyModel Analyzer **pma** generates an FSM from a model program by a process called *Exploration*.

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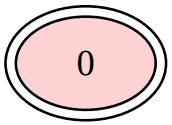

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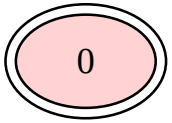


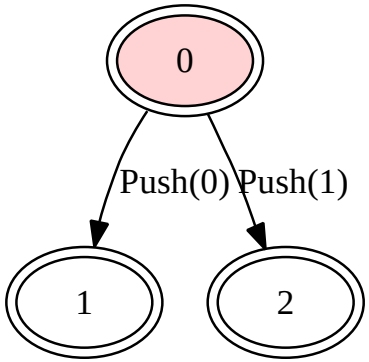

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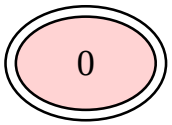


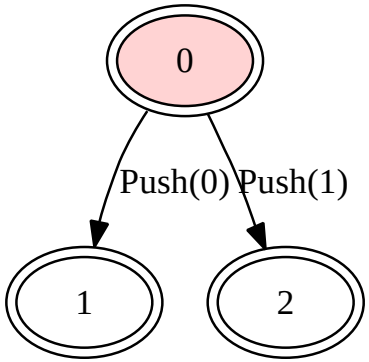


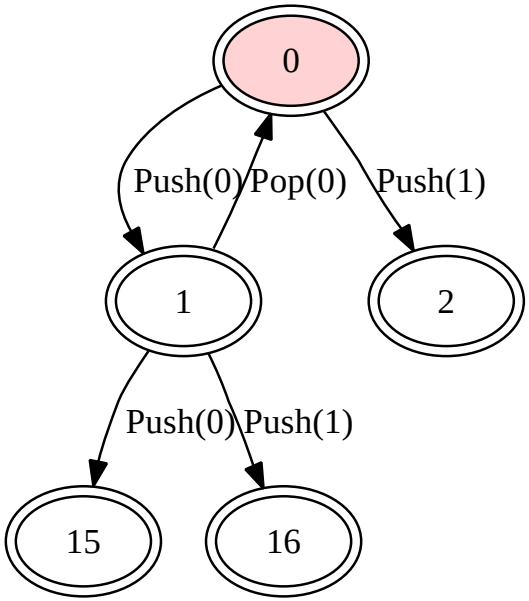

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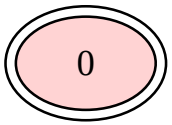
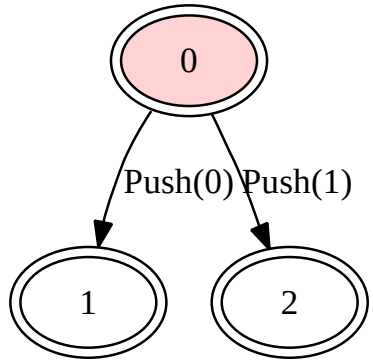
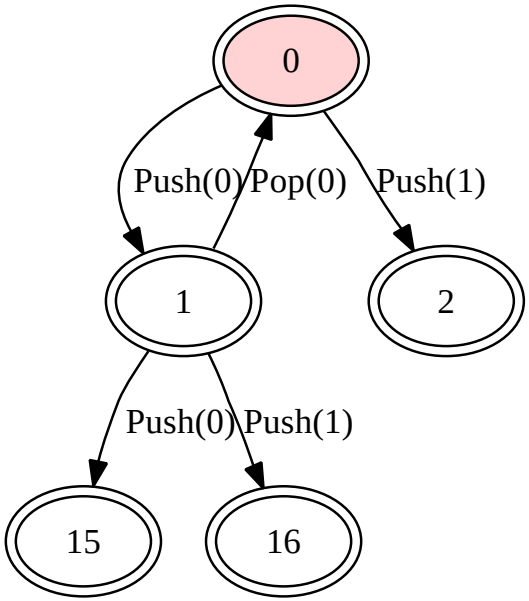
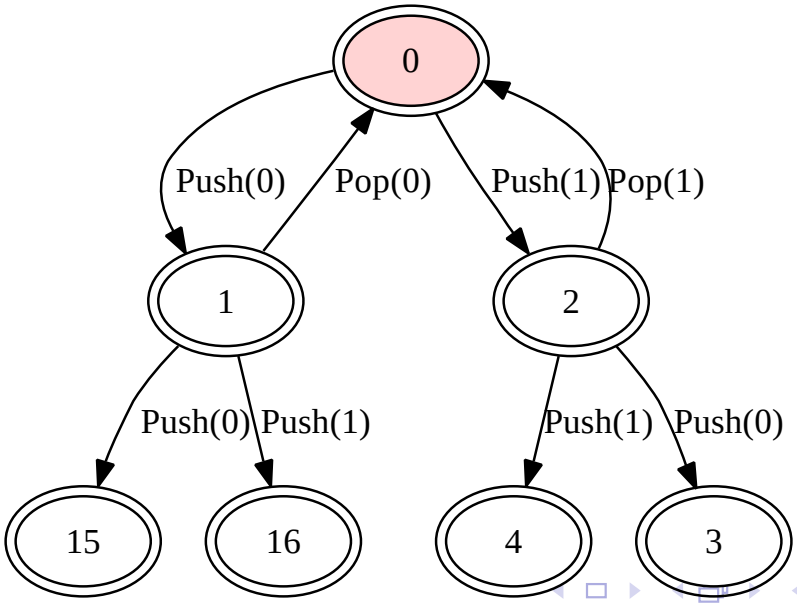


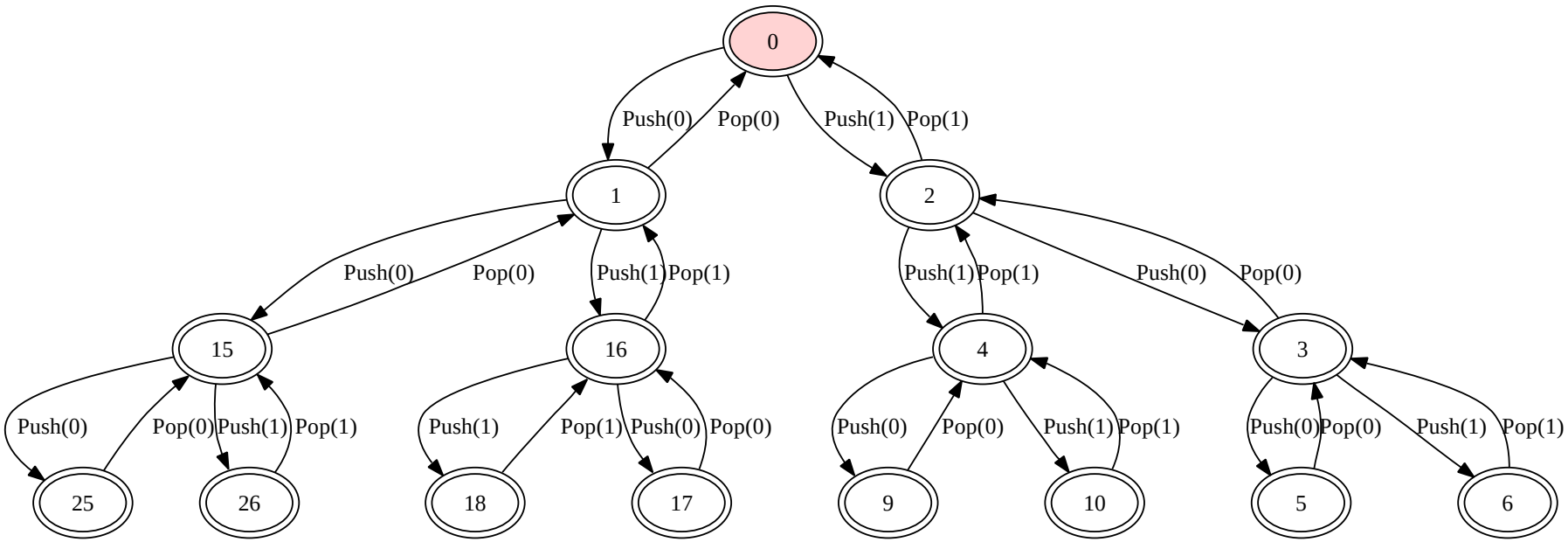

*etc ...*

# Exploration

We must limit exploration of infinite programs. Here we define a finite *domain* to limit the width of the graph, and a *state filter* to limit its depth.

```
domains = { Push: {'x':[0,1]} }

def StateFilter():
  return len(stack) < 4
```



# Strategies

Test generation can select the next enabled action at random, or use an optional *strategy* to select an action that increases coverage according to some measure.

```
> pmt.py Stack
Push(1,)
Push(2,)
Push(2,)
Push(1,)
Pop(), 1
Pop(), 2
Pop(), 2
Push(2,)
Push(1,)
Push(1,)
```

```
> pmt.py Stack
 -g ActionNameCoverage
Push(1,)
Pop(), 1
Push(2,)
Pop(), 2
Push(1,)
Pop(), 1
Push(2,)
Pop(), 2
Push(1,)
Pop(), 1
```

```
> pmt.py Stack
 -g StateCoverage
Push(1,)
Push(2,)
Push(2,)
Push(1,)
Push(1,)
Push(1,)
Push(2,)
Push(2,)
Push(1,)
Push(1,)
```

`ActionNameCoverage` and `StateCoverage` are included in PyModel. You can also code your own custom strategy.

# Composition

We need *scenario control* to limit test runs to scenarios of interest.

PyModel uses *composition*, a versatile technique combines two or more models to form a new model, the *product*.

$$M_1 \times M_2 = P$$

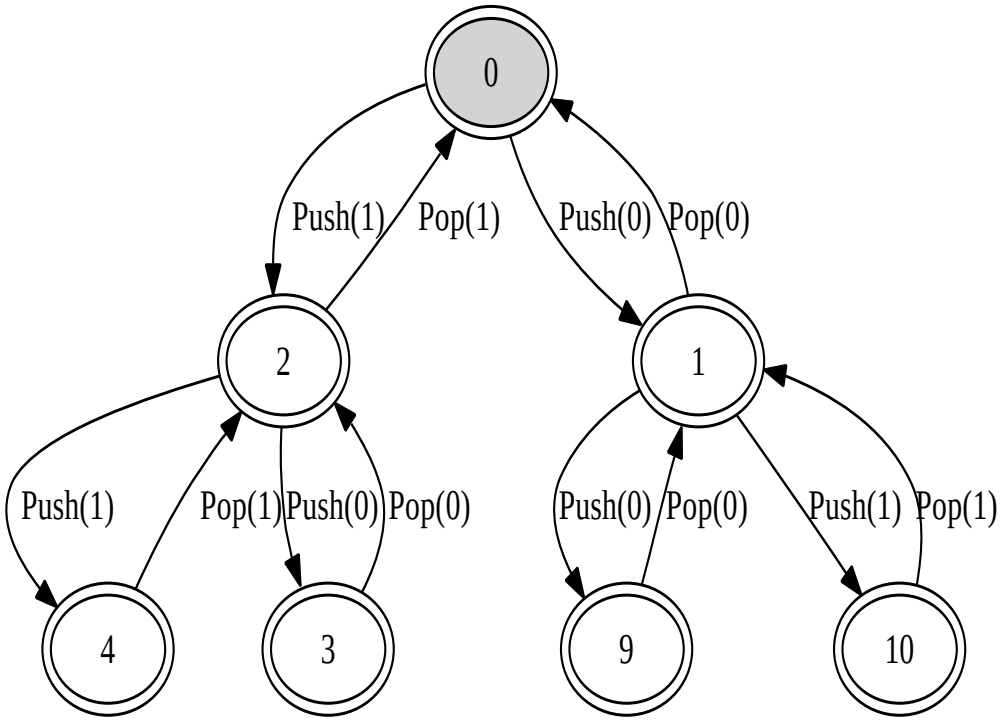
Usually we combine a *contract model program* (with action functions, etc.) with a *scenario machine*, an FSM.

$$Contract \times Scenario = Product$$

Composition can also be used for validation, program structuring, etc. ...

# Composition

Composition synchronizes shared actions.



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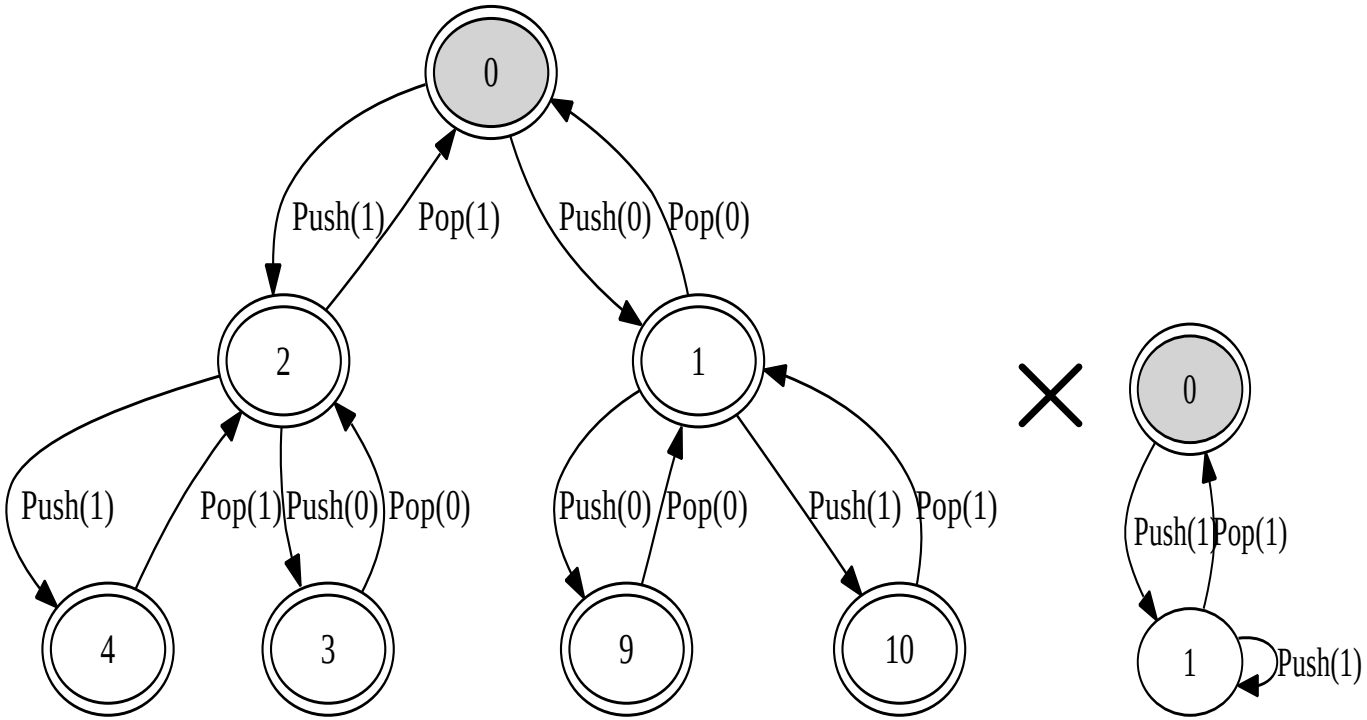

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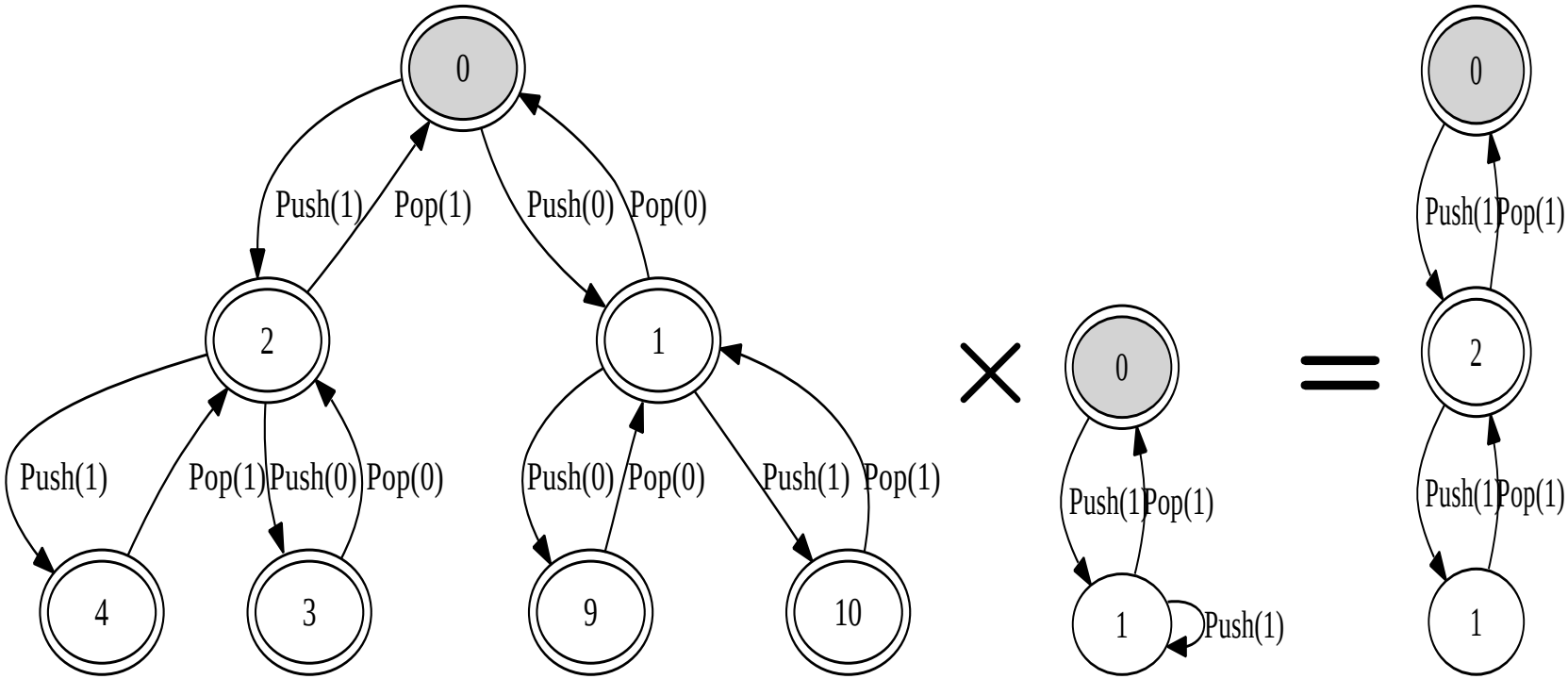
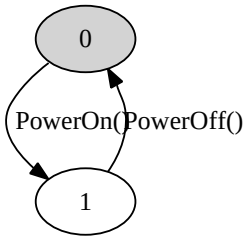



This usually has the effect of restricting behavior.

# Composition

Composition interleaves unshared actions.



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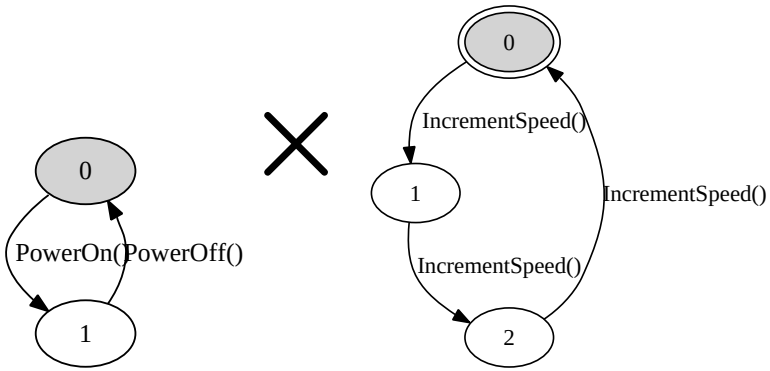

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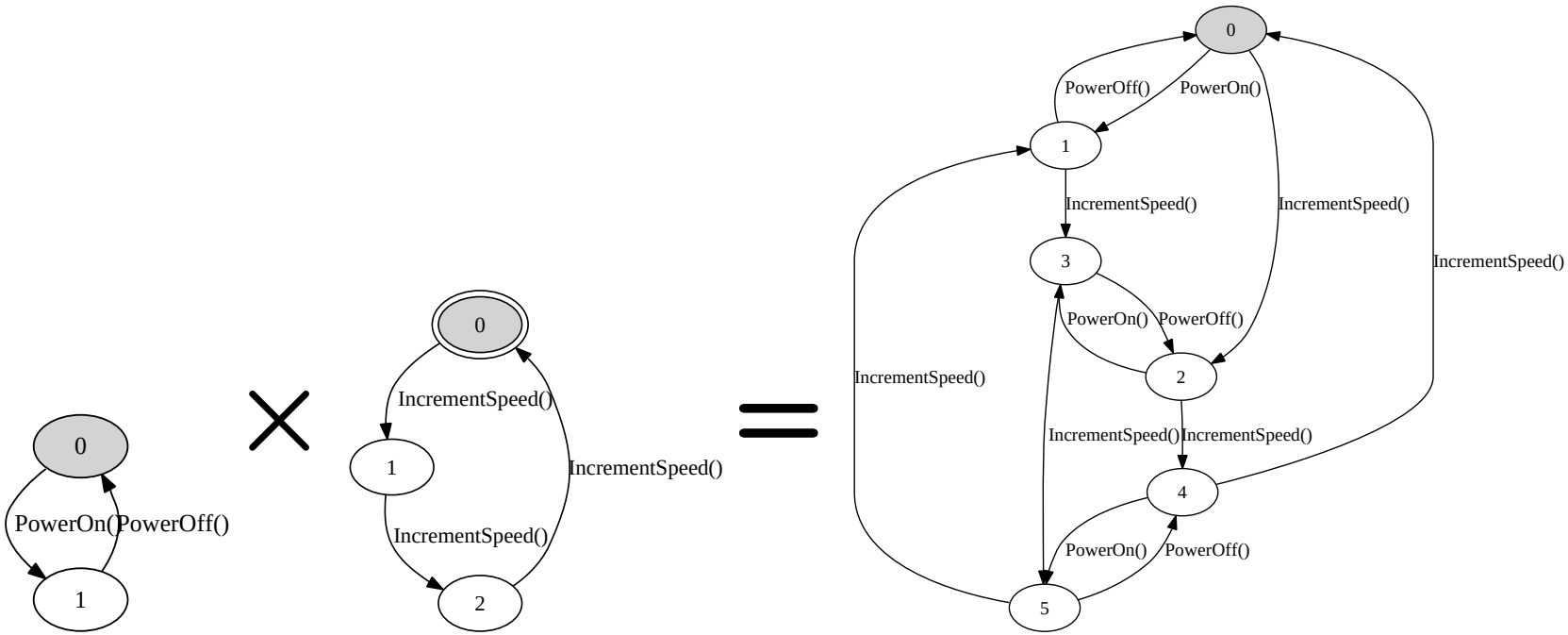
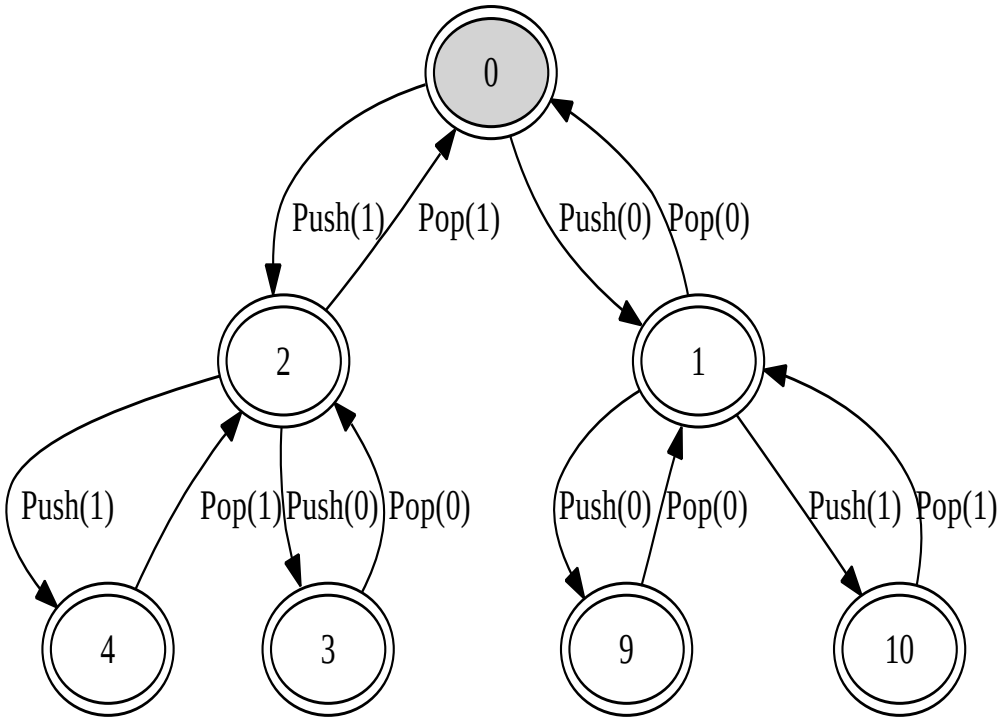



This usually has the effect of adding behavior.

# Validation

Composition with a scenario can help validate a model program.



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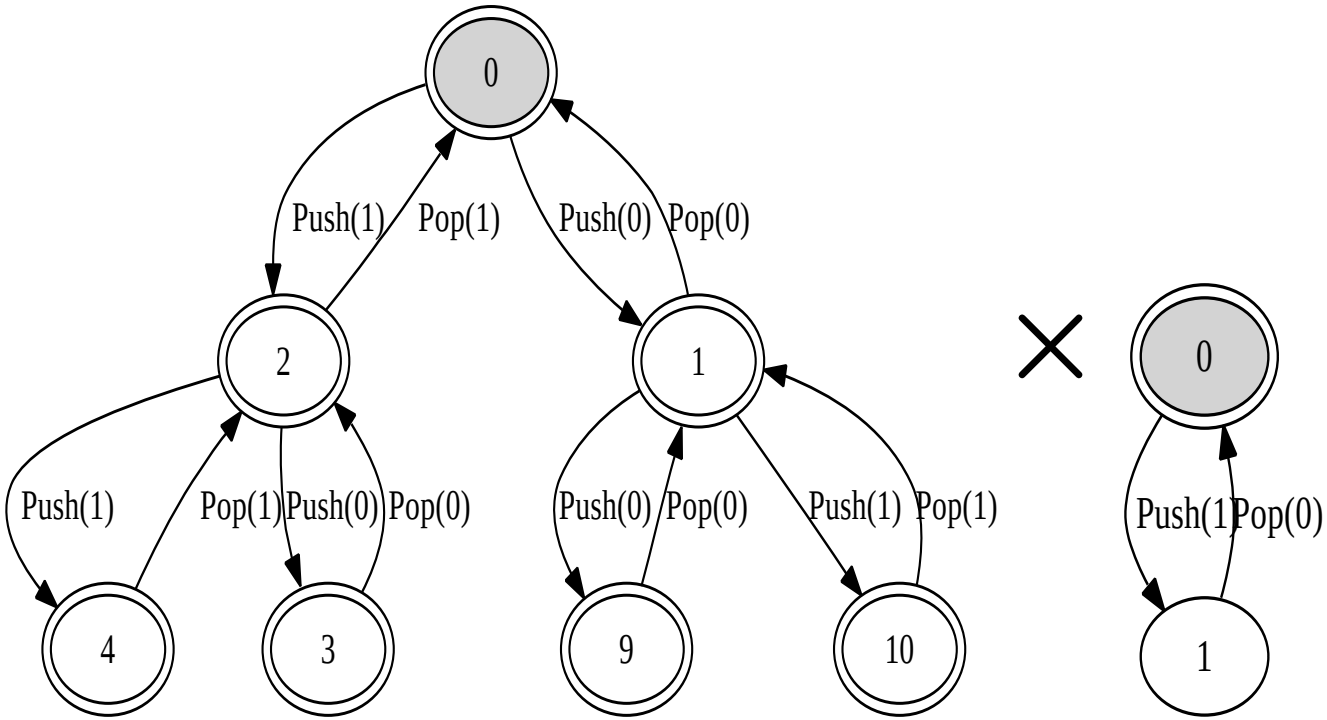

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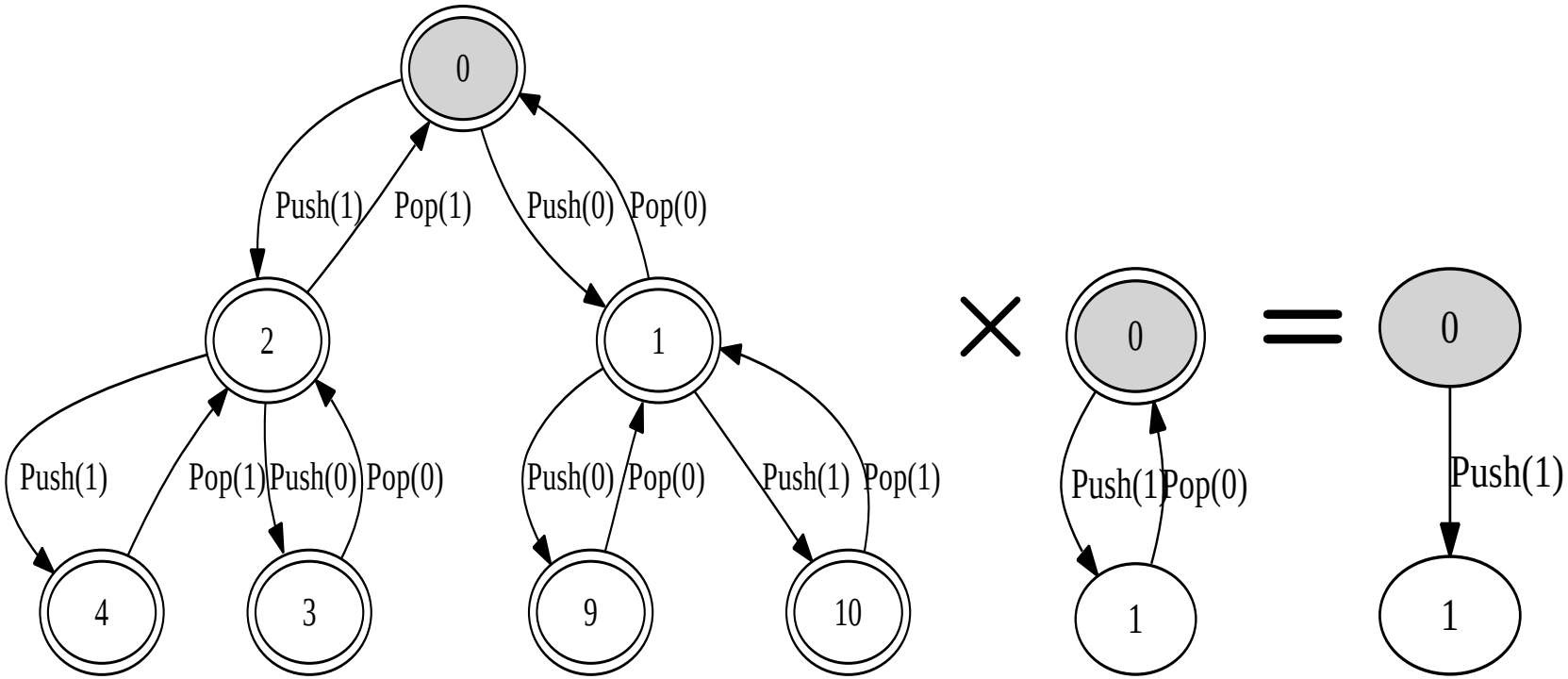
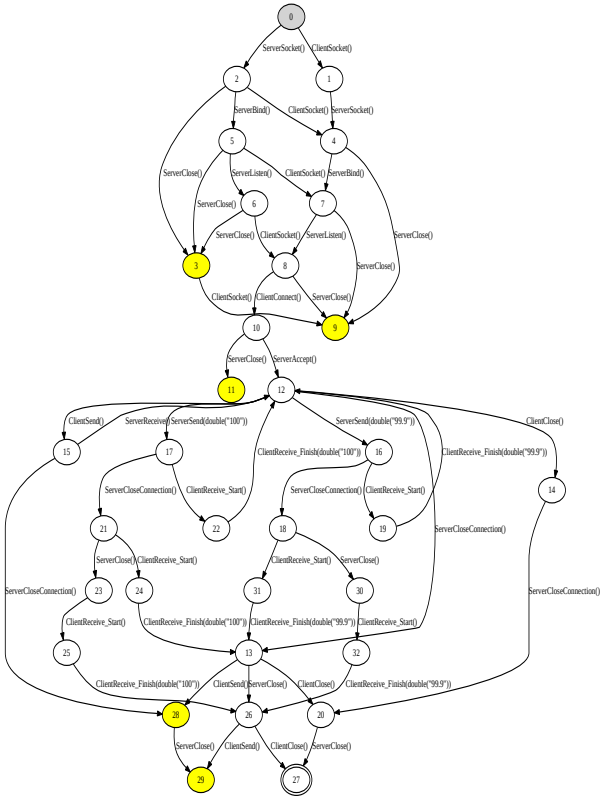



The product shows whether the model program can execute the complete scenario. Does the product reach an accepting state?

# Scenario Control

In this example we compose the model program with a scenario machine to eliminate redundant startup and shutdown paths.



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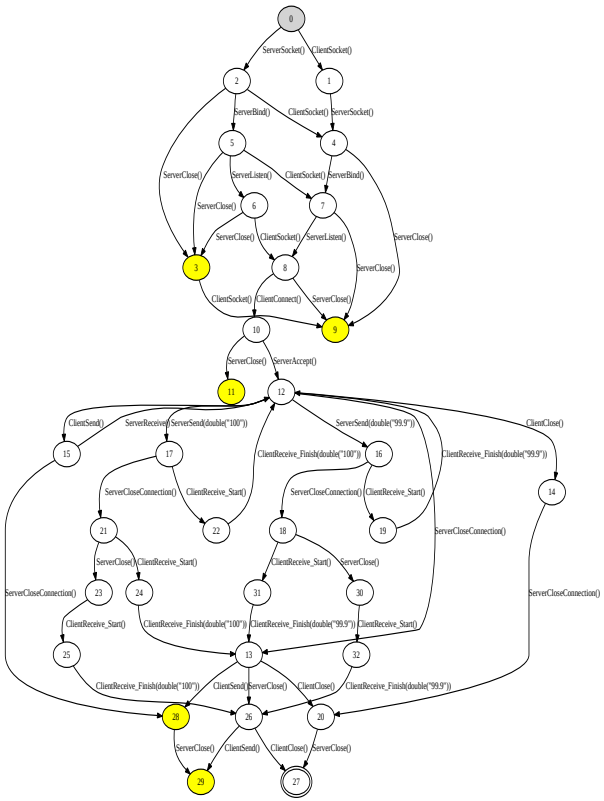

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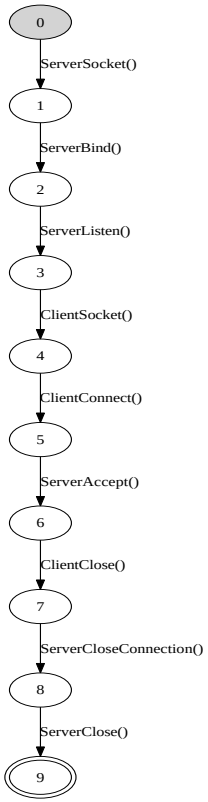

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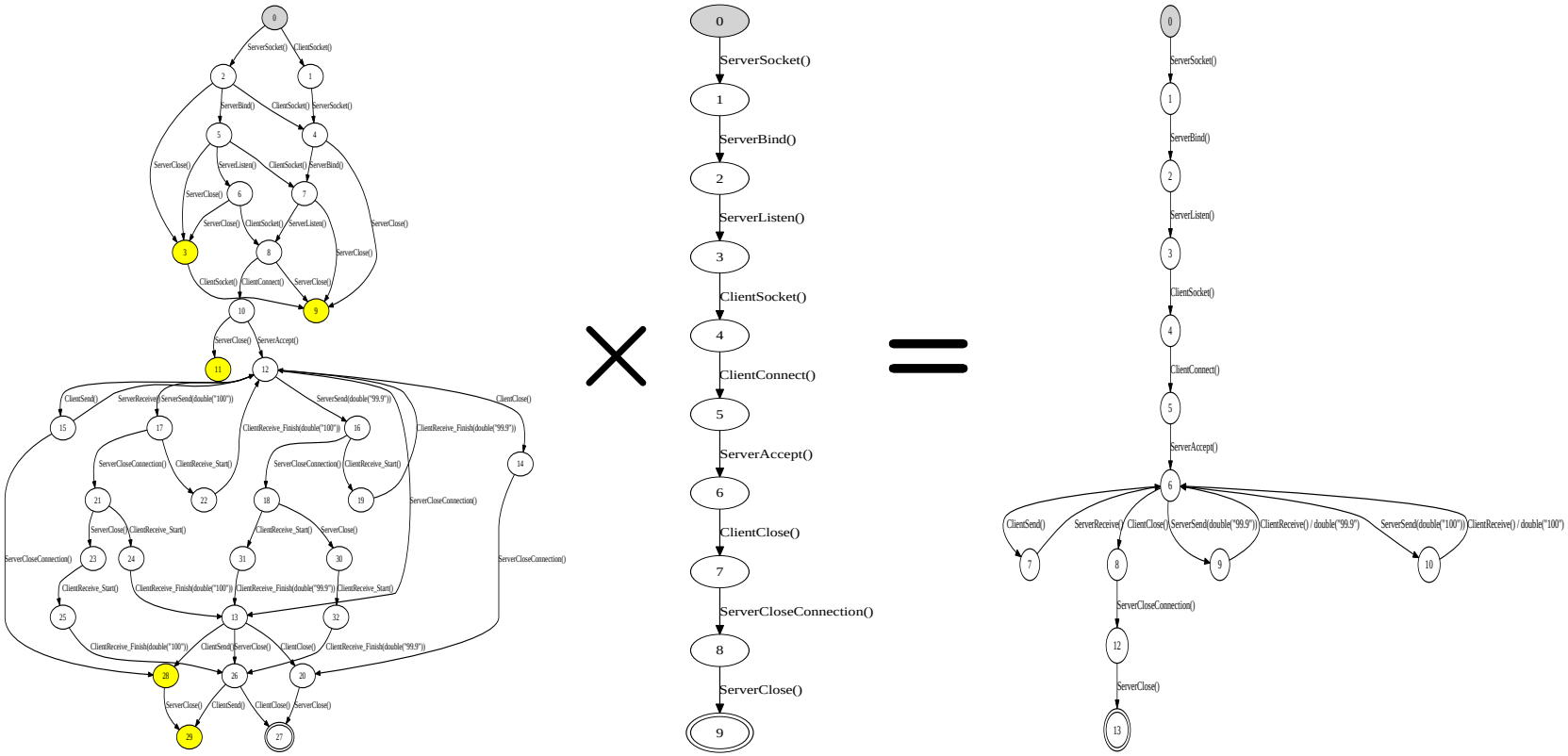



Now the product will only generate interesting traces.

# Test Harness

Executing tests requires a harness (or adapter) to connect the model to the implementation. In PyModel a test harness is called a *stepper*. Its core `TestAction` function contains a branch for each action in the model.

```
def TestAction(aname, args, modelResult):
  ...

  if aname == 'Initialize':
    session = dict() # clear out cookies/session IDs from previous session

  elif aname == 'Login':
    user = users[args[0]]
    ...
    password = passwords[user] if args[1] == 'Correct' else wrongPassword
    postArgs = urllib.urlencode({'username':user, 'password':password})
    page = session[user].opener.open(webAppUrl).read() # GET login page
    ...
    if result != modelResult:
      return 'received Login %s, expected %s' % (result, modelResult)

  elif aname == 'Logout':
    ...
```

# On-the-fly Testing

*On-the-fly testing* generates test cases as the test run executes. It overcomes some disadvantages of offline test generation.

- No FSM is generated, needn't finitize
- Test runs can be indefinitely long, nonrepeating

Especially

- Handles nondeterminism — responds to the nondeterministic choice that the implementation actually made!

This last requires an *asynchronous stepper* that distinguishes between *controllable actions* (functions the stepper can call) and *observable actions* (events the stepper can detect).

# Implications

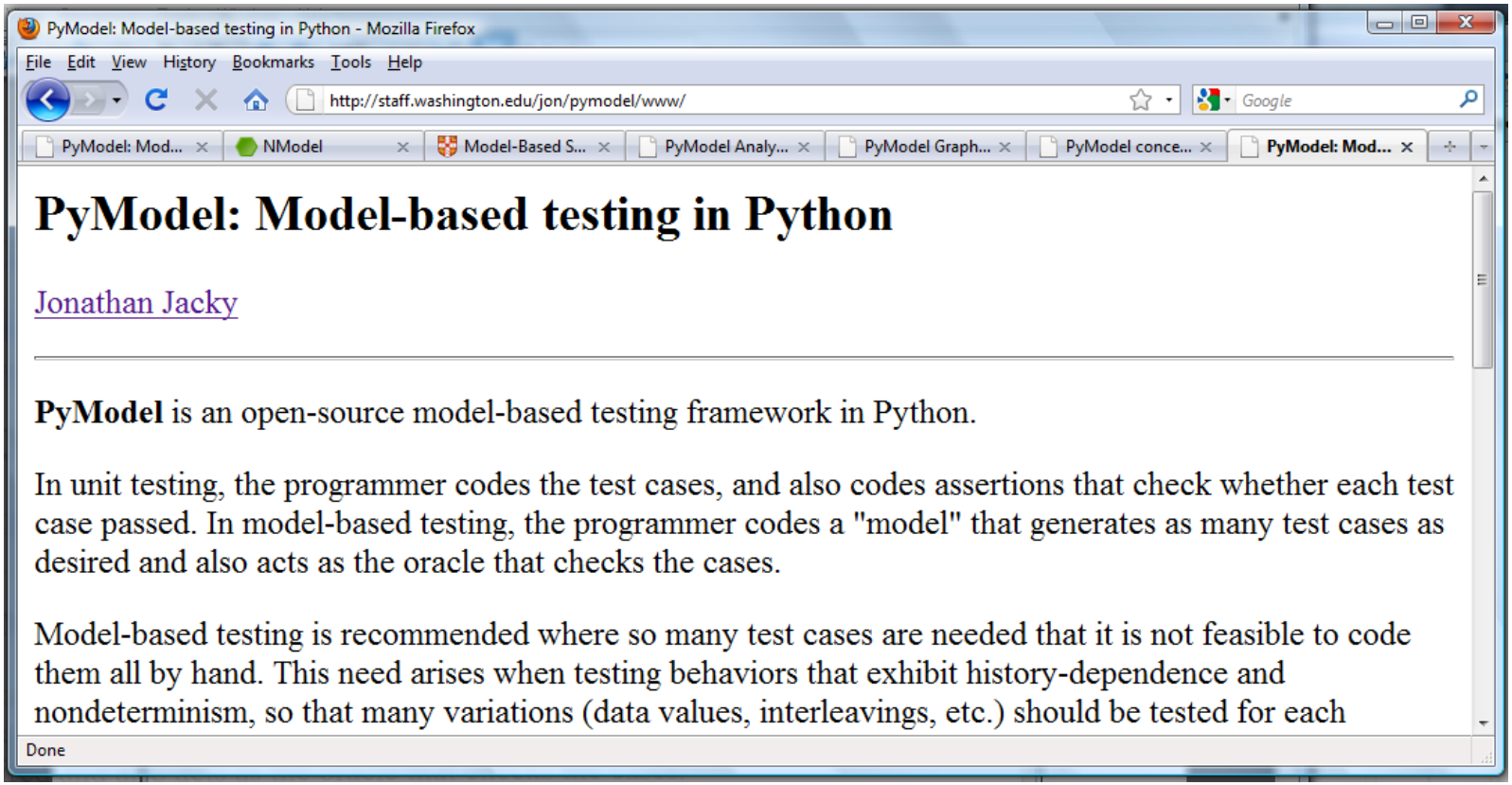
Model-based testing can encourage different approaches to testing.

- Encourages on-the-fly testing — but test runs may not be reproducible.
- Extends testing to noninvasive monitoring or *run time verification* — if the harness supports observable actions, the tester can check log files or monitor network traffic for conformance violations.
- Enables better integration of design analysis with testing — exploration is like *model checking*, can check for *safety*, *liveness*, and temporal properties.

A rational workflow might be to write the model *before writing the implementation*, analyze and tweak the design, then implement and test.

# Download PyModel

PyModel is an open-source model-based testing framework.




http://staff.washington.edu/jon/pymodel/www/