User Guide

OSMO Tester

MBT tool

v3.0

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NOTE: You may wish to check the tutorials for a bit more concrete and practical introductions.

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# Introduction

OSMO Tester is a model-based testing (MBT) tool. It uses a state-machine style notation to describe the system under test (SUT) from the testing perspective. This test model of the expected system behavior is provided by the human expert (user) and used by the tool as a basis for automatically generating test cases for the SUT.

In this context, MBT is about modeling the behavior of a system in terms of what actions the system can have and how they impact the system state. A test generation tool is then used to generate tests from this model instead of writing separate test cases by hand. The test model defines the set of possible test steps, and the tool generates test cases by forming varying compositions of these steps. The state of the model then defines when a test step is allowed to occur, practically providing a “correct” ordering of available test steps. In other contexts the test steps in the model could also be referred to as transitions and the model described as a state-machine over the system behavior.

An example of this is shown in Figure 1 for a simple vending machine. In this example, there are two basic test steps. One is for inserting money, and the other is for vending (which produces the bottle). In order to be able to get a bottle, one first has to insert the required amount of money, which in this case is 100 cents or more, with a bottle cost of 100 cents. In this case, the potential test steps are “insert money” and “vend”. These take different parameters and are allowed at different times. Insert money takes the parameter of how much money (coin type) is inserted. It is allowed always. Vending takes no parameters but is only allowed when 100 cents or more have been inserted. Similarly, we could disallow the “insert money” step if there are no bottles left in the machine.



Figure 1. A ”classic” state-machine for a vending-machine.

The MBT tool generates test cases based on the possible steps at any given time. The state of the model defines the possible steps, and in this case the state would be the amount of money inserted and the number of available bottles. Inserting money increases the model state variable that defines how many cents have been inserted. Vending reduces the inserted money by 100 cents and produces a bottle as output, also reducing the number of available bottles by one.

The concrete test cases generated would then invoke the SUT with these inputs and check for the expected outputs (bottles, changes in inserted cents, …).

# Modeling notation

This section describes the OSMO Tester modeling notation in terms of an example of the vending-machine described before and as commonly used in MBT literature (e.g., [1]). This vending machine accepts three types of coins (10 cents, 20 cents, 50 cents) and when a total of 100 cents has been inserted the “vend” action is enabled and can be invoked to produce a bottle. Figure 2 illustrates this as modeled with OSMO Tester.



Figure 2. Vending machine as an OSMO test model.

This model is an elaboration of the one shown in Figure 1 and as you can see, does not really describe the system from the perspective of a traditional state-machine notation. The circles are not states but rather actions (test steps) that can be performed and have some impact on the model state. The big circle in the middle shows the actual state of the system in terms of the model state variables (amount of inserted coins (cents) and number of available bottles). This state is modified by the actions/test steps that are the smaller circles on the bottom row.

As a simplified view, consider that the bottom row defines the possible test steps and the state defines when they are allowed to be taken. The dotted lines show how each transition affects the global state that is composed of two variables, *coins* and *bottles*. For example, inserting 10 cents increases the amount of coins inserted in the overall state by 10. The solid lines show a transition being taken from a given state, with possible guard statements associated with it. There is only one guard statement shown in this model, saying that the *vend* transition can only be taken when there are 100 or more coins available and one or more bottles available (bottles > 0).

In this example the state itself is rather simple. It is a composition of two variables, coins and bottles. Specific state conditions for test coverage such as having generated enough tests for covering requirements for vending with enough bottles, no bottles and enough or not enough coins can be covered by different test generation algorithms and configurations. Notations for defining requirements to be covered in test generation also exist and will be discussed in later sections.

The test models for OSMO Tester are in practice executable programs written in the Java programming language. In the MBT terminology these can be referred to as model programs (a term borrowed here from [2]). The specific model elements for the tool are identified based on a set of specific annotations. Listing 1 illustrates the OSMO Tester notation for the vending-machine example.

public class VendingExample {

private final Scripter scripter;

private int coins = 0;

private int bottles = 10;

@TestSuiteField

private TestSuite testSuite;

public VendingExample() {

scripter = new Scripter(System.out);

}

@Guard

public boolean gotBottles() {

return bottles > 0;

}

@BeforeTest

public void start() {

coins = 0;

bottles = 10;

int tests = testSuite.getTestCases().size()+1;

System.out.println(“Starting test:”+tests);

}

@AfterSuite

public void done() {

int tests = testSuite.getTestCases().size()+1;

System.out.println(“Total tests generated:”+tests);

}

@TestStep("10cents")

public void insert10cents() {

scripter.step("INSERT 10");

coins += 10;

}

@TestStep ("20cents")

public void insert20cents() {

scripter.step("INSERT 20");

coins += 20;

}

@TestStep("50cents")

public void insert50cents() {

scripter.step("INSERT 50");

coins += 50;

}

@Guard("vend")

public boolean allowVend() {

return coins >= 100;

}

@TestStep("vend")

public void vend() {

scripter.step("VEND ("+bottles+")");

coins -= 100;

bottles--;

}

@EndCondition

public boolean end() {

return bottles <= 0;

}

@Post

public void checkState() {

scripter.step("CHECK(bottles == "+bottles+")");

scripter.step("CHECK(coins == "+coins+")");

assertTrue(coins <= 100);

assertTrue(coins >= 0);

assertTrue(bottles >= 0);

}

public static void main(String[] args) {

OSMOConfiguration.setSeed(55);

OSMOTester tester = new OSMOTester(new VendingExample());

tester.generate();

}

}

Listing 1. Example vending machine in OSMO notation.

Here we see a number of the core model annotations being used. The following annotations are supported:

* @Guard: Defines a check that needs to pass for an associated transition to be considered as enabled.
* @Transition: Defines a transition that can be taken by the test generation algorithm to execute a test step.
* @TestStep: Same as above, but we call it a test step and not a transition.
* @Pre: Defines a method that is executed before associated transitions.
* @Post: Defines a method that is executed after associated transitions.
* @EndCondition: Defines a check that when it returns true it causes the current test generation to stop and the generation to continue with the next test in the suite.
* @EndState: Defines a check that needs to return true to allow for test generation to stop. Once a test generation algorithm has signaled test generation to stop, it continues until this returns true (if this is present).
* @BeforeTest: Called before a test case is generated.
* @AfterTest: Called after a test case generation has finished.
* @BeforeSuite: Called before any test cases in the test suite are generated.
* @AfterSuite: Called after all test cases in the test suite have been generated.
* @RequirementsField: Defines a field that holds a test requirements object.
* @TestSuiteField: Defines a field that is used to hold test generation history information.
* @Variable: Identifies a variable value to be stored before and after a test step is taken.
* @LastStep: A final step (transition) to be executed at the end of each test.
* @GenerationEnabler: When using OSMO Explorer, these are called to switch the model into concrete test generation mode.
* @ExplorationEnabler: When using OSMO Explorer, these are called to switch the model into exploration mode.



Figure 3. Generation flow with annotation elements.

Figure 3 shows a high-level overview of how the different annotations are processed by the test generation engine. Note that only the annotations matter, the naming of the methods themselves does not matter. However, some constraints on the method and field signature are as follows:

* @Guard: Method must return Boolean value. Method must not take any parameters.
* @Transition: Method must not take any parameters.
* @TestStep: Method must not take any parameters.
* @LastStep: Method must not take any parameters.
* @GenerationEnabler: Method must not take any parameters.
* @ExplorationEnabler: Method must not take any parameters.
* @Transition: Method must not take any parameters.
* @BeforeTest: Method must not take any parameters.
* @AfterTest: Method must not take any parameters.
* @BeforeSuite: Method must not take any parameters.
* @AfterSuite: Method must not take any parameters.
* @Pre: Method must not take any parameters or take a single parameter of type Map<String, Object>.
* @Post: Method must not take any parameters or take a single parameter of type Map<String, Object>.
* @EndCondition: Method must return Boolean value. Method must not take any parameters.
* @EndState: Method must return Boolean value. Method must not take any parameters.
* @RequirementsField: Field type must be Requirements. Value must be non-null.
* @TestSuiteField: Field type must be TestSuite. Value must be null (will be set by the generator).
* @Variable: Field can be of any type. If it implements the VariableValue interface, the value returned by the value() method is stored.

**@BeforeSuite**

During test generation, first any methods annotated with the @BeforeSuite annotation are executed on the model. These are executed only once during test generation before any tests are generated. Practically here, suite refers to all generated test cases and a test case refers to a set of test steps. Useful for setting up stuff for the overall test generation process.

**@BeforeTest**

Before a test case is generated, all methods annotated with @BeforeTest are executed. New test case generation is considered to start at suite start, and when a test end condition returns true signaling the end of a test case, while at the same time the suite end condition returns false, signaling that more test cases should be generated. For example, in Listing 1 there is one method called start() with this annotation. In this example, this resets the model state between generated tests.

**@Guard**

When test generation is progressing, the test generation engine calls all @Guard annotated methods to identify the current set of enabled transitions. Any guard method that returns false is considered to disable all associated transitions, even if other guard methods for that transition return true. If no guard is associated to a transition, the transition is considered to be enabled always. A guard is associated to a specific transition based on their identifiers. An identifier is associated to a guard annotation as @Guard(“transitionname”), where transitionname is a String matching the name of a transition to which it is associated. If @Guard is present with no name given, it is associated to all transitions in the model. It is also possible to associate a single guard to several transitions using the notation of @Guard({“name1”, “name2”}) where the associated transitions are given as a list of strings. Every guard method is always executed to identify all enabled transitions between test steps (transitions executed). Note that defining a guard named @Guard(“all”) equals defining it as @Guard, as this matches the unnamed @Guard annotation in the internal OSMO Tester representation.

**@Transition & @TestStep**

The actual test steps to be generated are represented by the @Transition or @TestStep annotated methods in the model. The enabled transitions are identified by their associated guard statements as described above. Transitions are named similar to guards, i.e. @Transition, @Transition(“name”), @Transition({“name1”, “name2”}). Similar to guards, transitions named @Transition(“all”) are forbidden. The set of enabled transitions are identified by the associated guard statements that return true at a given time. From this set of enabled transitions the chosen test generation algorithm then picks one to be executed as the next test step. As mentioned, in a simplified view of test generation, transitions can be seen to describe test steps.

It is also possible to give weights to transitions, using the notation of @Transition(name=”name”, weight=2). In this case, name is the name of the transition and the weight is used with different weighted algorithms to define how many times the transition should be taken in relation to other available transitions. The default value for a weight is 10, so any transition with undefined weight has a weight of 10. When multiple transitions are enabled, a test generation algorithm that takes weights into account will favor the ones with more weight more often. For example, if transitions A has a weight of 1 and transition B a weight of 2, and both are always enabled at the same time, transition B will be taken twice as often as transition A. Examples of a weighted algorithms are the WeightedRandomAlgorithm and WeightedBalancingAlgorithm implementations. Note that the choice is still based on several factors with only a higher probability given to the ones with higher weights (and with the balancing algorithm, the number of times the transition has been taken also impacts the choice).

**Example for @Guard+@Transition**

For example, in Listing 1, there is a transition and a guard named “vend”. The guard checks that this transition can only be taken if there are 100 coins or more inserted. After this becomes true, the vend transition is enabled. There is also a general guard statement in the form of the method gotBottles(). This makes sure that any transition can only be taken (coins inserted, vending applied) when there are some bottles in the machine. Notice that in this case this is practically a pointless guard since there is an end condition in the model making sure this state is never achieved. However, it is included here to illustrate the concept. We could also add a new transition called “return deposit” that would return all inserted coins and this could be enabled even when no bottles are present. In this case the guard for having no bottles would become @Guard({“10cents”, “20cents”, “50cents”, “vend”}). That is, it would not include the “return deposit” transition, which would be allowed when no bottles are left.

**@LastStep**

After a test case is destined to end, before @AfterTest is handled, all @LastStep methods are called. Difference with the @AfterTest is that this one is executed as a part of the test case and thus failed assertions and other such exceptions will not stop who test generation but fail the test case. Can be useful, for example, if generating a large input for one-shot execution as the result of the test model (e.g. transformation testing). In such a test case we might wish to run the test input and evaluate the test oracle once at the end, while the test steps would build the overall input over time.

**@Pre**

Before a transition is taken, all associated @Pre annotated methods are executed. These are named and associated to transitions similar to guard statements. If the method has the Map parameter, a single Map instance is passed for each pre-method. This is the same instance each time for the same transition invocation. Thus any values set in the pre-methods are accessible in all post-methods associated to that transition using the Map. This can be useful for writing a test oracle that compares the state before and after the transition.

**@Post**

After a transition is taken, all associated @Post annotated methods are executed. These are named and associated to transitions similar to guard statements. If the Map parameter is provided, it will be the same as was provided for any @Pre method for that transition. Thus any values set in the pre-methods are accessible in all post-methods associated to that transition. Any global variables in the model class tagged as @Variable will be stored into this Map as well (automatically by the generator).

**@EndCondition**

When all @Post-methods associated to the currently executed test step (transition) have been executed, the current test case is evaluated for stopping. At this point any method annotated with @EndCondition is executed. If any one of them return true, the current test generation is stopped. If no end condition returns true, the test generation end conditions as defined for the generator are executed to evaluate if the test case generation should be continued. If test generation is evaluated to continue, the test generation engine will re-iterate with evaluating all guards for enabled transitions and continue again from there, picking another transition and so on. In Listing 1 there is one end condition that makes sure test generation is ended when there are no bottles present as otherwise the generator would throw an exception as there would be no enabled transition left in this state.

**@AfterTest**

When test generation for a single test case is finished, all methods annotated with @AfterTest are executed. Once this has been executed, the generator test suite end condition is evaluated to define whether to continue with generating the next test case or to stop all test generation. If test generation is continued, the generator continues with the next test case and the @BeforeTest annotated methods.

**@AfterSuite**

Once all test generation is finished (test suite end condition tells the engine to stop), all @AfterSuite annotated methods are executed.

**@GenerationEnabler**

When OSMO Explorer is used, the tool needs to vary the model between “exploration” and “concrete generation” modes. Methods tagged with @GenerationEnabler are invoked before entering the concrete generation mode. Typically this will set the actual concrete scripter into use in the model vs the exploration scripter.

**@ExplorationEnabler**

When OSMO Explorer is used, the intent is to vary the model between “exploration” and “concrete generation” modes. Methods tagged with @ExplorationEnabler are invoked before entering the exploration mode. Typically this will set the exploration (simulating/null) scripter into use in the model vs the concrete generation scripter.

# Test generation

As described, the purpose of OSMO Tester is to generate test cases from the given test model based on the annotations described above. Note that the specific order of executing several available guards or other annotated methods is no explicitly defined. It should be deterministic (at least when using a specific generator version) but beyond that you should make no assumptions that they would be executed in specific order (such as the ordering in your text editor for the source code from top to bottom).

Besides the annotations, it is also possible to configure OSMO Tester using a set of configuration methods. This includes defining a set of the test suite end conditions, a set of test case end conditions, a test generation algorithm, and enabling or disabling debug logging. As noted before, it is also possible to add specific elements to the model that are relevant for the different test generation algorithms, such as giving weights to transitions and defining requirements to be covered in the model.

In Listing 1 the test generation is initiated with the following the following fragment:

public static void main(String[] args) {

OSMOTester tester = new OSMOTester(new VendingExample());

tester.generate();

}

}

However, we can also define a set of additional attributes such as

public static void main(String[] args) {

1 OSMOTester osmo = new OSMOTester();

2 osmo.addModelObject(new VendingExample());

3 osmo.addTestEndCondition(new Length(3));

4 osmo.addSuiteCondition(new Length(2));

5 osmo.setAlgorithm(new BalancingAlgorithm());

6 osmo.setDebug(true);

7 osmo.generate();

}

}

The lines here are the following:

1. Creates the OSMOTester test generation engine.
2. Adds a new model object to be parsed for generation. You can add as many as you like, and they will be combined together where transitions, oracles, guards, etc. are matched across the provided objects. Some people call the result a “flattened” model because they are treated as if written inside the same class.
3. Sets the end condition object for ending generation of single test cases. The condition used here causes each generated test case to have 3 steps (that is, after executing three transitions, the generator stops). The default condition used, if no end condition is by the user, is to end after generating a minimum of 1 test step, with 5% probability.
4. Sets the end condition object for ending generation of all tests (the test suite). The condition used here causes the generator to generate 2 tests. The default condition is set to end after generating a minimum of 1 test cases, with 10% probability.
5. Sets the test generation algorithm. By default this is set to a RandomAlgorithm that randomly takes one of the available transitions. The BalancingAlgorithm used here takes previously uncovered transitions if available, and balances further choices by always taking one of the available transitions with the least coverage so far.
6. This enables more verbose debug printing in System.out and in a log file.
7. This invokes the test generation engine to generate tests from the given model objects with the defined configuration.

Note that you must always specify the randomization seed before generation as shown in Listing 1. This is to make it explicit that if you do not specify one, it will randomized and different runs will produce different results. Most of the times this is not the target behavior. You can still randomize the seed yourself if so desired.

# Special model elements

As noted before, there are some special model elements that only make sense when combined with specific test generation algorithms. These include weighted transitions, tags and state variable definitions. It also includes the annotations for the OSMO Explorer tool. The OSMO Explorer tool is an extension on OSMO Tester available separately, focusing on providing different optimizations.

**Weighted Transitions**

For example, we could emphasize the test step for 10 cents by changing it in the following way:

@TestStep(**name="10cents", weight=20**)

public void insert10cents() {

scripter.step("INSERT 10");

coins += 10;

}

With this change, the 10 cents transition would now be taken twice as often where the others are taken once (assuming the transition is enabled). The default weight if none is specified is 10. To make the transition useful, we would also need to use a matching weighted test generation algorithm:

osmo.setAlgorithm(new WeightedRandomAlgorithm());

**Requirements**

We could also use tags in the model to ensure that one of the generated test cases will cover a case where all bottles have been emptied in the vending machine:

private int bottles = 10;

@RequirementsField

private Requirements req = new Requirements();

...

public VendingExample() {

scripter = new Scripter(System.out);

req.add(“all bottles vended”);

}

...

@TestStep("vend")

public void vend() {

scripter.step("VEND ("+bottles+")");

coins -= 100;

bottles--;

if (bottles == 0) {

req.covered(“all bottles vended”);

}

}

In this case, we add requirements that should be covered in the constructor with the add() method. We mark them covered in test generation with the covered() method. The given parameters (requirement name) must match in order for the requirements to be considered as covered. New requirements for coverage can be added at any time before the generation is started with the osmo.generate() method. In most cases, they can even be added during generation but this is not guaranteed to work.

In order for test generation to continue until this requirement is covered, we must again apply a matching test generation algorithm:

osmo.addSuiteEndCondition(new RequirementsCoverage());

With this, the test suite generation will go on until the requirement is covered. Note that this can mean it going on forever if the combinations are incorrect (such as length of 3 for a test case, which will never reach this state). In the case of the vending machine example, this is also not a very useful overall configuration as it will likely cause the generation of a very large set of test cases before randomization creates a long enough one to completely run out of bottles. In practice, such goals are best achieved with customized model configuration, modularized models, and a diverse set of simple model objects. Another option is to use OSMO Explorer if available.

**Composition of End Conditions**

In addition to specifying specific end conditions, it is also possible to compose several end conditions into one. This can be done using the And and Or end condition classes. Alone these have no meaning but together with others can combine several end conditions into one. For example, the following creates an end condition that specifies that test cases need to have a minimum length of 5 steps (transitions taken in the model), maximum of ten steps (transitions) and the probability of 25% for having a length of 6-9 transitions taken (ending before max is reached):

EndCondition min = new Length(5);

EndCondition max = new Or(new Length(10), new Probability(0.25d));

EndCondition minMax = new And(min, max);

osmo.addTestEndCondition(minMax);

To put it different, the test must have a minimum of 5 steps AND (maximum of 10 steps OR randomized probability of 25% becomes true in any step after 5). OK, practically the probability to end is 25% at each step and not overall in all the 5 steps (it is actually higher since each step adds to the probability) but anyway...

**Data-Flow Modelling**

The items described above mainly relate to defining different aspects related to the control-flow of the model (the test sequence generation). However, it is also important to note the need to generate data for parameter values of the test sequences. Support for this is provided by elements in the osmo.tester.model.dataflow package. Each component in this package can generate values fitting the data values it represents, as well as to check if the given value is part of the given set. These are performed in each case by the next() and evaluate(Object) methods of each class. They also share common Input and Output interface implementations, allowing each to be replaced by other when references through the interfaces. These objects include the following elements:

* Boundary: Data at the boundaries of given range.
* CharSet: Set of defined characters, such as ASCII, valid XML content, and others.
* Text: Sequences of CharSet.
* ValueSet: Set of values containing any Java objects.
* ValueRange: Range of numerical values with a minimum and maximum.
* ValueRangeSet: A set of numerical ranges, possibly overlapping or not.

These objects are based on general test automation concepts (such as category-partitioning). You can also provide your own as you see best fit by implementing the Input and Output interfaces. If you want the OSMO Tester to make better use of them in optimization and test tracing, you can also extend the SearchableInput class in your own implementations, which will cause OSMO Tester to capture generated values in the test steps.

**BaseModel Class**

The code base also includes a BaseModel class, which can be extended to provide a test model. This gives access to the current test case being generated, the previous transition taken, and the test case identifier.

**State Variable Identification**

The @Variable annotation can be used to identify specific state variables in the model. If any model variables are described with this annotation, they will be taken by the generator to describe the model state at different points of time. The generator will not act on them but will store each variable value to every TestStep object stored in the TestSuite object (accessible in the model with @TestSuiteField annotation and directly in the test generation algorithms). Each TestStep object will then contain values for all these variables both before the transition that created the test step was taken and after the transition was taken. These values can be accessed using corresponding getter methods in the TestStep objects.

Similar to the values being stored to the TestStep object, they are also provided to all the @Pre and @Post methods if they are defined to have the Map<String, Object> parameters. In this case, the @Pre methods will get the values of the variables before the associated transition is taken and the @Post methods will get the values after the transition has been taken. The key in the map will be the variable name and the value will be the value of the object stored in the field. In case of primitives or Objects not implementing the VariableValue interface, the value stored is the raw value of the field. In case the field contains an Object implementing the VariableValue interface, the value() method of the interface will be called to provide a value to be stored.

The @Variable annotation is intended to be used for tagging primitive (as is) and custom values (with the VariableValue interface) in the model. It captures the variable name either from as the name defined in the source code for the variable or as a parameter to the annotation. The dataflow modeling objects provided with the OSMO Tester library are of type SearchableInput, which means the generator will actually capture all values they produce when their next() method is invoked even when not annotated as @Variable. In fact, annotating them so has little useful effect, except storing the last value they generated before and after a transition.

**JUnit integration**

It is also possible to run tests using JUnit integration. Check the JUnit online testing with OSMO Tester tutorial for more information.

# Report builders

There are some components in the osmo.tester.reporting package that can generate various types of reports for you. These include coverage and test data reporters in HTML and CSV format. HTML reports can be handy for browser based sharing of results, and CSV reports for Excel based sharing. These reporters work in different ways, either studying the information stored in the test suite object or by giving you and interface to store data while the tests are executed.

Coverage reports are based on coverage data stored in the TestSuite object. Here is an example:

CSV csv = new CSV(test, testCoverage, fsm);

String report = csv.getTransitionCounts();

This will now have created the report that is stored in the “report” variable. Do with that as you wish. There is a more detailed example in the OSMO Tester examples package.

# Customization of algorithms and other components

In addition to the existing test generation algorithms, suite end conditions and other components provided with OSMO Tester, customized versions of these components can also be created.

To create a test generation algorithm that traverses the model object, you must implement the FSMTraversalAlgorithm interface. To define your own test suite or test case generation end conditions, you must implement the EndCondition interface. More information on these can be found in their Javadocs and in the project source code.

# Calendar Tutorial

The OSMO Tester source code includes several smaller examples and one bigger example. The bigger example is an example for generating tests for a calendar application. The calendar used as a test subject is a simple example of a calendar component implemented in Java and also included in the OSMO Tester calendar example source code. The example can be found under the examples source code in package osmo.tester.examples.calendar.

This has several subdirectories/packages, which are the following

* osmo.tester.examples.calendar.scripter. Examples of online and offline scripters for the calendar example.
* osmo.tester.examples.calendar.testapp. The test subject in this example.
* osmo.tester.examples.calendar.testmodel. The test models for this example.

The tested application provides the following calendar functionality and constraints

* A calendar can be created, with a user associated to it.
* One user can have one calendar associated.
* Tasks can be added to the calendar, a task has a description and a date.
* Meetings can be added to the calendar, a meeting has a description, a location, a start date, and an end date.
* Existing meetings can be linked to new users, making the added users participants in the meeting, while the user for whom it was originally created is the organizer of the meeting.
* Tasks can be deleted.
* Meetings can be deleted. If the meeting is deleted from a participant, it has no effect on other users and their calendars. If the meeting is deleted from an organizer, the same meeting is also deleted from all linked participants.
* Task and meeting descriptions and locations are String data types.
* Task and meeting related times are described using Java Date data type.

In order to demonstrate the different OSMO Tester features, the following model elements are provided:

* adding and removing meetings for organizer.
* adding and removing tasks.
* creating meetings that overlap other meetings and tasks that overlap meetings.
* attaching meetings to an organizers calendar, creating participants for the meetings.
* error handling of invalid input.
* test oracles to assert correct tasks and meetings are present in the calendar.

**Base model for creating meetings**

The base model for the calendar includes the creation and removal of meetings. It looks like this:

public class CalendarMeetingModel {

/\*\* The global model state, shared across test models. \*/

private final ModelState state;

/\*\* The scripter for creating/executing the test cases. \*/

private final CalendarScripter scripter;

private final PrintStream out;

private final Tags reqs = new Tags();

public CalendarMeetingModel(ModelState state, CalendarScripter scripter) {

this.state = state;

this.scripter = scripter;

this.out = System.out;

}

public CalendarMeetingModel(ModelState state, CalendarScripter scripter,

PrintStream out) {

this.state = state;

this.scripter = scripter;

this.out = out;

}

@BeforeTest

public void setup() {

state.reset();

scripter.reset();

out.println("-NEW TEST");

}

@AfterSuite

public void dump() {

scripter.write();

}

@Transition("Add Meeting")

public void addEvent() {

String uid = state.randomUID();

Date start = state.randomStartTime();

Date end = state.randomEndTime(start);

ModelEvent event = state.createEvent(uid, start, end);

out.println("--ADDMEETING:" + event);

scripter.addEvent(event);

}

@Guard("Remove Meeting")

public boolean guardRemoveOrganizerEvent() {

return state.hasEvents();

}

@TestStep("Remove Meeting")

public void removeOrganizerEvent() {

ModelEvent event = state.getAndRemoveOwnerEvent();

out.println("--REMOVEMEETING:" + event);

scripter.removeEvent(event.getUid(), event.getEventId());

}

}

Here we see a number of basic elements for the model as expressed in the OSMO Tester annotations:

@BeforeTest: This method resets the model state between generated tests, and also resets the scripter to initiate the creation of a new test case.

@Transition(“Add Meeting”): This method creates a new meeting with a set of generated data, and scripts the its creation with the help of the defined scripter. This transition has no guard associated, meaning that it can be taken by the generator at any time.

@Guard(“Remove Meeting”): This method ensures that a step to remove a meeting is only generated when meetings exist (have been previously added).

@TestStep(“Remove Meeting”): This method adds a test step that removes a meeting. More precisely, it removes a meeting from the organizer. This is because in other partial models, we add an option to link already created meetings to new users through their calendars. Thus, this will remove the meeting from the organizers calendar. In practice, if the meeting also has participants, the meeting will also be deleted from their calendars since this simulates the full cancellation of the meeting.

The two variables of the model shown here are:

ModelState: This incorporates the state of the test model. The elements of the model state could also be directly embedded into this single class file but here we prefer to encapsulate it in its own object to provide for more cohesive structure and also to be able to share the state across several partial models.

CalendarScripter: This defines an interface for scripting the results. There are two different implementations of a scripter in this example. One is an online scripter, another one is an offline scripter. The role of these scripters is to relay the test step commands to the test framework and through there to the test target.

Now we are ready to run the generator to generate test cases from the model. Here is how we can do this:

/\*\*

\* This is used to execute the calendar example.

\*

\* @param args command line arguments, ignored.

\*/

public static void main(String[] args) {

OSMOTester osmo = new OSMOTester();

ModelState state = new ModelState();

CalendarScripter scripter = new OnlineScripter();

osmo.addModelObject(new CalendarMeetingModel(state, scripter));

osmo.generate();

scripter.write();

}

Note that the last part of scripter.write() is only needed for offline scripting. In any case, this should execute the model with OSMO Tester using the online scripter. As a result the calendar application is created in memory and all input data is provided and output data checked. The sequences should be visible on the system console.

**Scripter**

You may wonder what happens in the scripter to make the magic of actually executing the test cases happen. You can find the full source code for this class in the examples package. Here is the listing from the OnlineScripter for the relevant parts:

public class OnlineScripter implements CalendarScripter {

/\*\* Maps user identifiers to CalendarUser objects. \*/

private Map<String, CalendarUser> users =

new HashMap<String, CalendarUser>();

public OnlineScripter() {

}

/\*\*

\* Used to reset the scripter between generated tests.

\*/

@Override

public void reset() {

users.clear();

}

/\*\*

\* Helper to get the calendar object for the given user.

\*

\* @param uid User whose calendar we want.

\* @return The calendar.

\*/

private CalendarApplication getCalendarFor(String uid) {

CalendarUser user = users.get(uid);

if (user == null) {

user = new CalendarUser();

users.put(uid, user);

}

return user.getCalendar();

}

@Override

public void addEvent(ModelEvent event) {

CalendarApplication calendar = getCalendarFor(event.getUid());

CalendarEvent calendarEvent = calendar.addEvent(event.getStart(),

event.getEnd(), event.getDescription(), event.getLocation());

event.setEventId(calendarEvent.getId());

}

@Override

public void removeEvent(String uid, ModelEvent event) {

CalendarApplication calendar = getCalendarFor(uid);

calendar.removeEvent(event.getEventId(), false);

}

This is an online scripter, meaning that it will practically create the test calendars for requested users, create meetings (events in the code) for these calendar objects and so on as needed.

For the remainder of this tutorial we will describe the online scripter, but for offline scripting, there is also an example in the osmo.tester.examples.calendar.scripter.offline package for scripting the calendar example through the Robot Framework. This is based on the generic Robot Framework scripter available in the osmo.tester.scripter.robotframework package. Running with the offline scripter produces the script in HTML format into the directory where started with the given filename.

**Model state object**

The model state is stored in the ModelState object. Here is the relevant part for the meeting creation:

public class ModelState {

/\*\* Test users with calendars. \*/

private Collection<String> uids = new ArrayList<String>();

/\*\* Events for each user. \*/

private Map<String, Collection<ModelEvent>> userEvents =

new HashMap<String, Collection<ModelEvent>>();

/\*\* Used to generate unique identifiers for events. \*/

private AtomicInteger eventCount = new AtomicInteger(0);

/\*\* Used to generate start times between January 2000 and December 2010. \*/

private ValueRange<Long> startTime;

public ModelState() {

}

/\*\*

\* Used to reset the state between test generation.

\*/

public void reset() {

uids.clear();

userEvents.clear();

eventCount = new AtomicInteger(0);

int users = cInt(1, 5);

Text names = new Text(4,7);

names.setName("name");

for (int i = 1; i <= users; i++) {

this.users.add(names.next());

}

Calendar start = Calendar.getInstance();

start.set(2000, 0, 1);

Calendar end = Calendar.getInstance();

end.set(2010, 11, 31);

startTime = new ValueRange<Long>(start.getTimeInMillis(), end.getTimeInMillis());

}

public String randomUID() {

return oneOf(uids);

}

public ModelEvent createEvent(String uid, Date start, Date end) {

int count = eventCount.incrementAndGet();

String description = "event" + count;

String location = "location" + count;

Collection<ModelEvent> events = getOrCreateEvents(uid);

ModelEvent event =

new ModelEvent(uid, start, end, description, location);

events.add(event);

return event;

}

private Collection<ModelEvent> getOrCreateEvents(String uid) {

Collection<ModelEvent> events = userEvents.get(uid);

if (events == null) {

events = new HashSet<ModelEvent>();

userEvents.put(uid, events);

}

return events;

}

public boolean hasEvents() {

return userEvents.size() > 0;

}

public ModelEvent getAndRemoveOrganizerEvent() {

Collection<ModelEvent> uniqueEvents = getUniqueEvents();

ModelEvent event = oneOf(uniqueEvents);

Collection<String> toRemove = new HashSet<String>();

for (String uid : userEvents.keySet()) {

Collection<ModelEvent> events = userEvents.get(uid);

events.remove(event);

if (events.size() == 0) {

toRemove.add(uid);

}

}

for (String uid : toRemove) {

userEvents.remove(uid);

}

return event;

}

Here we see how the state is reset between test runs, how input is given in terms of picking a valid user identifier for test generation, how meetings are created for testing, and how meetings are removed. Notice that when actions are performed that modify the state on the test target, also the model state needs to be modified similarly. For this reason, the removal of a meeting needs to remove the meeting from the state but also to return it so that the scripter can be used to remove the same meeting from the actual test target. This keeps the model state in a consistent state where it can be assumed to match the test target at all times.

This example also illustrates the use of one of the input data model objects provided with OSMO Tester. This is the ValueRange object. As time in computers is typically expressed in terms of milliseconds from a given data as a long valued integer, this value range has minimum value as the number of milliseconds to create the date 1st of January, 2000. As the upper range it has the number of milliseconds to create the date 31st of December, 2010. Depending on the configured data generation strategy for this model object, the .next() method can then be used to create new values in this range, effectively providing us with dates between January 1st, 2000 and December 31st, 2010. Similar data model objects can be found in the OSMO Tester in the osmo.tester.model.dataflow package.

**Adding test oracles**

A following question is, what are the models good for, as currently they do not check anything. A test case is not very useful if it cannot make a verdict about correctness of what happened. We can add a new partial model for test oracles to provide an example:

public class CalendarOracleModel {

/\*\* The global model state, shared across test models. \*/

private final ModelState state;

/\*\* The scripter for creating/executing the test cases. \*/

private final CalendarScripter scripter;

public CalendarOracleModel(ModelState state, CalendarScripter scripter) {

this.state = state;

this.scripter = scripter;

}

@Post

public void genericOracle() {

for (String uid : state.getUids()) {

Collection<ModelEvent> events = state.getEventsFor(uid);

scripter.assertUserEvents(uid, events);

}

}

}

Now, what have here is the same model state and the same scripter. There is only one annotation here:

@Post: This method now loops through the calendars for all users, checking that the meetings for those users as stored in the actual calendar object match those generated in the model. Since the @Post annotation has no name defined it equals to @Post(“all”), meaning that it will be executed after each @Transition tagged methods. This way the generated tests will keep checking the results all the time, after each test step.

The matching part of the online scripter is:

@Override

public void assertUserEvents(String uid, Collection<ModelEvent> events) {

CalendarApplication calendar = getCalendarFor(uid);

Collection<CalendarEvent> calendarEvents = calendar.getEvents();

if (events == null) {

if (calendarEvents != null && calendarEvents.size() > 0) {

fail("Events are null in model, should be empty also in calendar");

}

return;

}

assertEquals("Number of events in model vs calendar", events.size(),

calendarEvents.size());

for (ModelEvent modelEvent : events) {

String description = modelEvent.getDescription();

Date start = modelEvent.getStart();

Date end = modelEvent.getEnd();

boolean found = false;

for (CalendarEvent calendarEvent : calendarEvents) {

if (!calendarEvent.getDescription().equals(description)) {

continue;

}

if (!calendarEvent.getStart().equals(start)) {

continue;

}

if (!calendarEvent.getEnd().equals(end)) {

continue;

}

found = true;

}

assertTrue("ModelEvent not found on calendar:"+modelEvent, found);

}

}

Here we use the JUnit test framework to provide us with some online assertion capabilities, illustrating how any Java libraries can be used with the models. The assertEquals() and assertTrue() methods come from the JUnit framework and evaluate that the given reference value matches the actual observed value. Similar assertions can be built for any values observed or expected to be observed at any point in the model code. This includes any return values, any accessible global state value or any other values available. In the end it is just Java code with special features added by the OSMO Tester (kind of like a framework).

To execute OSMO Tester with the new partial model added, we do the following:

/\*\*

\* This is used to execute the calendar example.

\*

\* @param args command line arguments, ignored.

\*/

public static void main(String[] args) {

OSMOTester osmo = new OSMOTester();

ModelState state = new ModelState();

CalendarScripter scripter = new OnlineScripter();

osmo.addModelObject(new CalendarMeetingModel(state, scripter));

osmo.addModelObject(new CalendarOracleModel(state, scripter));

osmo.generate();

scripter.write();

}

**Testing error handling behavior**

The above examples test the expected correct behavior of the system. In addition, it is commonly of interest to use to test that the error handling of the test target works as expected. Here is an example of a partial model for testing the error handling functionality of the calendar example:

public class CalendarErrorModel {

/\*\* The global model state, shared across test models. \*/

private final ModelState state;

/\*\* The scripter for creating/executing the test cases. \*/

private final CalendarScripter scripter;

public CalendarErrorModel(ModelState state, CalendarScripter scripter) {

this.state = state;

this.scripter = scripter;

}

@Transition("Remove Meeting That Does Not Exist")

public void removeMeetingThatDoesNotExist() {

System.out.println("--REMOVEMEETINGHATDOESNOTEXIST:");

scripter.removeMeetingThatDoesNotExist(state.randomUID());

}

}

Here we have again the shared model state and scripter. Additionally, we have the transition:

@Transition(“Remove Meeting That Does Not Exist”): This tries to remove an event with an invalid identifier but with a valid user id. The corresponding code from the online scripter is:

@Override

public void removeMeetingThatDoesNotExist(String uid) {

CalendarApplication calendar = getCalendarFor(uid);

try {

calendar.removeMeeting("no such meeting", false);

fail("Removing a meeting that does not exist should fail.");

} catch (Exception e) {

//expected

}

}

Notice that here the event id given is “no such meeting” and since the meeting identifiers are always of form “meeting”+number, we know this will fail. Thus we expect to get an Exception, and fail the test if one is not observed. We could further assert that the exception includes the correct error message and other details as necessary.

Again, to execute OSMO Tester with the oracle and error handling partial models added, we do the following:

/\*\*

\* This is used to execute the calendar example.

\*

\* @param args command line arguments, ignored.

\*/

public static void main(String[] args) {

OSMOTester osmo = new OSMOTester();

ModelState state = new ModelState();

CalendarScripter scripter = new OnlineScripter();

osmo.addModelObject(new CalendarMeetingModel(state, scripter));

osmo.addModelObject(new CalendarOracleModel(state, scripter));

osmo.addModelObject(new CalendarErrorModel(state, scripter));

osmo.generate();

scripter.write();

}

**Adding tasks, event participants, and more**

In order to add support for tasks, meeting participants, and other elements, we create similar new partial models. Full source code for these can be found with the calendar model source code in the OSMO Tester package.

# Manual Drive

In addition to using automated test generation, OSMO Tester also comes with a simple interface to allow one to manually drive test generation (i.e. the user becomes the test generation algorithm). This can be instantiated by setting the test generation algorithm as ManualDrive such as:

public static void main(String[] args) {

OSMOTester osmo = new OSMOTester();

ModelState state = new ModelState();

CalendarScripter scripter = new OnlineScripter();

osmo.addModelObject(new CalendarMeetingModel(state, scripter));

osmo.addModelObject(new CalendarOracleModel(state, scripter));

osmo.addModelObject(new CalendarErrorModel(state, scripter));

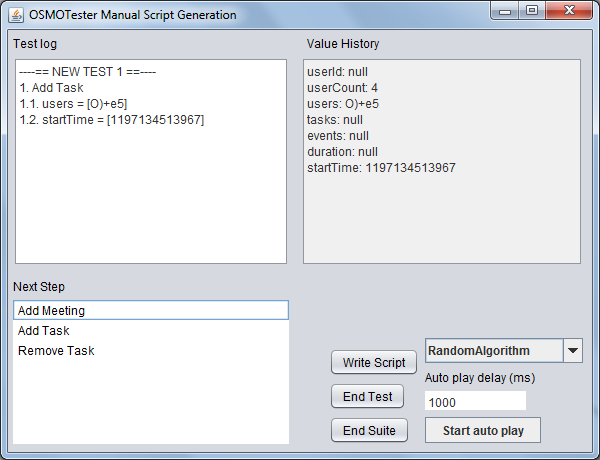
osmo.setAlgorithm(new ManualDrive());

osmo.generate();

scripter.write();

}

When this is executed, it will open up a window such as this:



Here the user can now choose which transition will be taken next in test generation. This choice is made by clicking on the list “Next Step” on the bottom left. This list is always updated to reflect the possible set of enabled transitions as seen by OSMO Tester. It is thus a reflection of the internals of the test generator and can also be useful for debugging models. On the top left “Test log” panel, the history of taken transitions is visible, with a higher number meaning a more recent test step. In the “Value History” panel on the top right, the latest values used for different data variables is shown. On the bottom right the user can start automated test generation using the chosen algorithm and with the given delay. The delay can be modified on the fly.

Any transitions executed through this “Manual Drive” are executed normally as any test model. Thus, as usual it will also generate the scripts or execute the test steps as specified in the model. The configuration used by OSMO Tester behind the scenes is exactly that which has been configured for it. Thus, with test end condition of length 3, this will also stop tests after three steps and start a new one and so on. Manual control for this can be added by using an instance of ManualEndCondition.

# Additional Concepts

While the above has discussed and described the basic features of OSMOTester, a few more notes on specific configurations can be interesting.

**Visualizations**

It is possible to provide specific visualizations of elements and statistics by using specific GenerationListener implementations from the visualizer module. These are such as tester.addListener(new TransitionBarChart()); or tester.addListener(new TransitionsPieChart());.

**Model Slicing**

OSMO Tester also has support for using the model as a textual domain-specific language. In this case, the transition and variable names form the words in the language grammar. For example:

SlicingConfiguration config = new SlicingConfiguration();

config.addStepMin("increase", 1);

config.addStepMin("decrease", 1);

DataCoverageRequirement cReq = new DataCoverageRequirement("counter");

cReq.addRequirement(3);

config.add(cReq);

config.setAlgorithm("random");

config.setModelFactory(

"osmo.tester.examples.slicing.TestModelFactory");

config.setSeed(233);

DSMMain.execute(config);

This defines that both the “increase” and “decrease” must be present in the generated tests at least one time.

The part that takes care of the actual execution is the SlicerMain class, which can also be invoked from the command line. In this case, a filename containing the slice definitions should be given as a parameter. For more information, check the Javadoc for the AsciiParser class.

For the user of MetaEdit+ DSM graphical modeling tool, check the MetaEdit+ examples in the OSMO version control.

**Test filtering**

The way that the slicing approach achieves the definition of minimum and maximum bounds of transitions and variables is through the use of StepCoverage and DataCoverage end conditions as well as MaxTransitionFilter filter. These can be used separately if desired, or as examples for creating custom filters.

# OSMO Explorer

OSMO Explorer is an extension for OSMO Tester that can be licensed separately. It focuses on providing different optimization approaches on top of OSMO Tester.

Automatically generating a lot of test cases can be a nice boost to test coverage, ease test maintenance and so on. But sometimes there is a limit to how many tests can be executed, the execution can be slow, hardware limited and so on. Using a combination of test generation algorithms and other components, a large number of tests can be generated. As OSMO Tester is mainly designed to help the user in test automation, the models can be written and generation guided quite effectively to produce the type of variation desired. This is also supported by the manually driven test generation, model slicing, model objects, and other elements. OSMO Explorer is an extension to OSMO Tester, containing a set of optimizer components that can be applied to generate a test suite optimized for a set of specified coverage criteria.

There are two types of optimizers provided with OSMO Explorer. The greedy optimizer produces test cases using the OSMO Tester as describe above, but continuing test generation until specific coverage criteria is achieved. This basic approach picks transitions to take based on the defined criteria and on the next steps available from the current state. The seconds approach is to use the online explorer, which systematically explores every possible path through the model up to a given depth and picks the most optimal test step for a test case up to this depth based on the given coverage criteria.

The following shows an example of running OSMO Explorer on the calculator example model in the OSMO Tester examples:

public class ExplorerMain {

public static void main(String[] args) {

DOTWriter.enabled = true;

ModelFactory factory = new CalculatorFactory();

OSMOExplorer osmo = new OSMOExplorer();

osmo.setSeed(55);

ExplorationConfiguration config =

new ExplorationConfiguration(factory, 3);

config.setMinSuiteLength(3);

config.setMinTestLength(5);

config.setPairsWeight(40);

config.setTransitionWeight(1);

config.setValueWeight(50);

osmo.explore(config);

}

}

What this does, it runs every possible path in the model up to the given depth, and chooses the path giving the highest score in terms of given coverage configuration as the next step. You can tune the parameters to produce test cases matching your goals more optimally. OSMO Explorer comes with a tutorial, Javadocs and examples for more information.

# Conclusions

OSMO Tester provides means to create test models and to generate test cases from these models. This document covered the basic concepts and notation of the tool. For more details, the reader is encouraged to check the OSMO Tester Javadocs. There are also more examples in the OSMO Tester source code under the osmo.tester.examples package and in the source code test directory in form of JUnit tests.

Contact information can be found on the project web site for questions.

# References

OSMO Tester home page, discussion forums & source code: <http://code.google.com/p/osmo/>