

Model-Based Testing

(DIT848 / DAT260)

Spring 2015

Lecture 11

EFSMs and Executable Tests (in ModelJUnit)

Gerardo Schneider

Department of Computer Science and Engineering
Chalmers | University of Gothenburg

Summary of previous lecture

- The Qui-Donc example
- Modeling Qui-Donc with an FSM
- Some simple techniques on how to generate tests from the Qui-Donc model
- EFSM
- The ModelJUnit library
- A Java "implementation" of an EFSM for the Qui-Donc example
 - Offline testing (not executable)

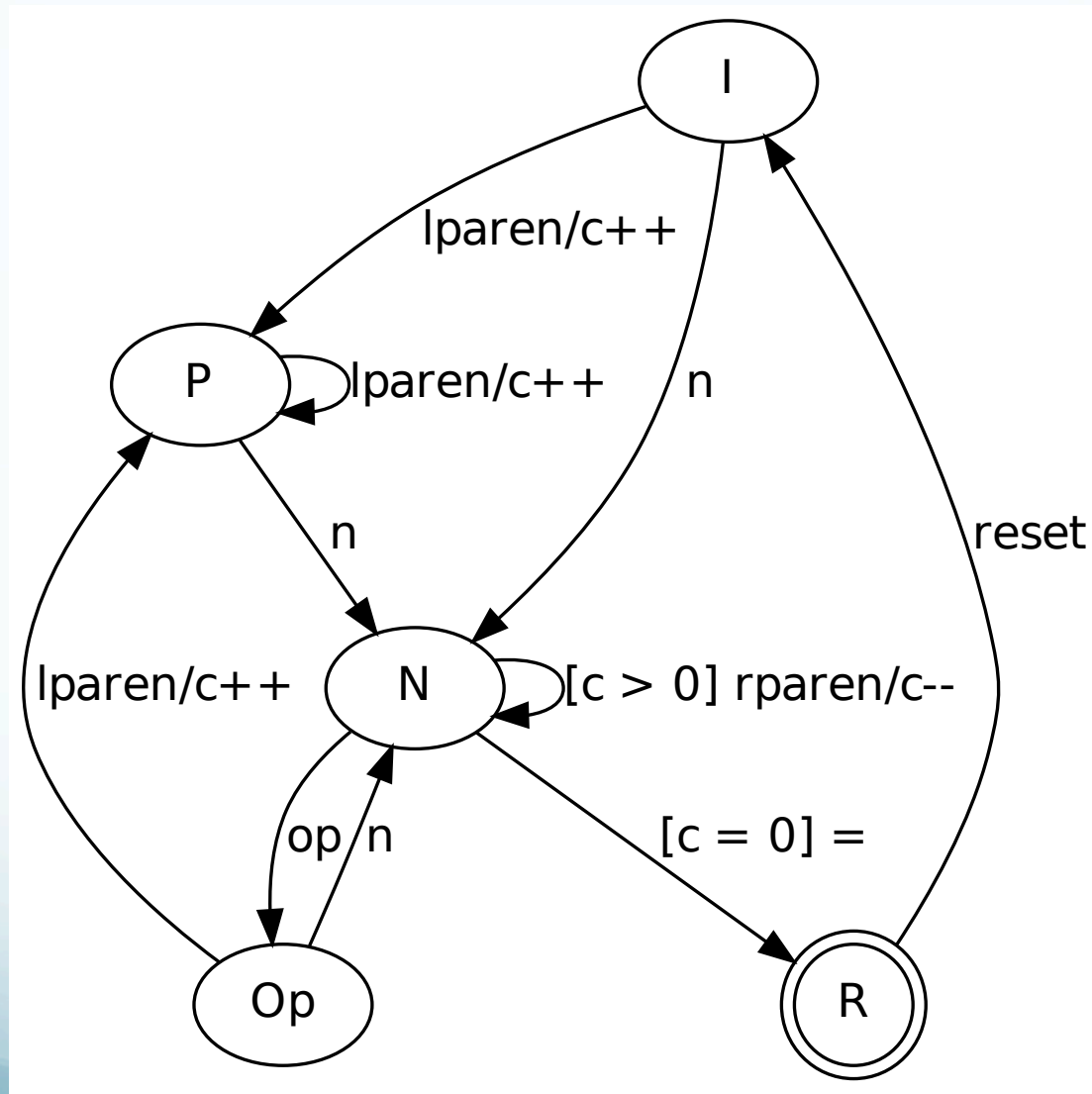
Outline

- More interactive exercises on building an EFSM
- Executable tests
- Online testing with ModelJUnit

EFSM for Calculator (v.1)

- Write an EFSM for a calculator accepting (positive) integers, different operators ($*$, $+$, $-$, $/$), a reset operation, and parenthesis
- Assume numbers are full integers (not a string of digits)
- Assume that there is no need to check for division by zero
- The result is given when entering "=" (no need to "calculate" the result)
- After pressing "=" the result should be given and the calculator is reset
 - I.e., it is not possible enter an expression "1+2=+4" and expect to get 7 as result (computing 1+2 first and adding 4 to the result)
- For this first version: Assume that inputs with only one operator between two operands is accepted (i.e. something like "1+*2" is not accepted)

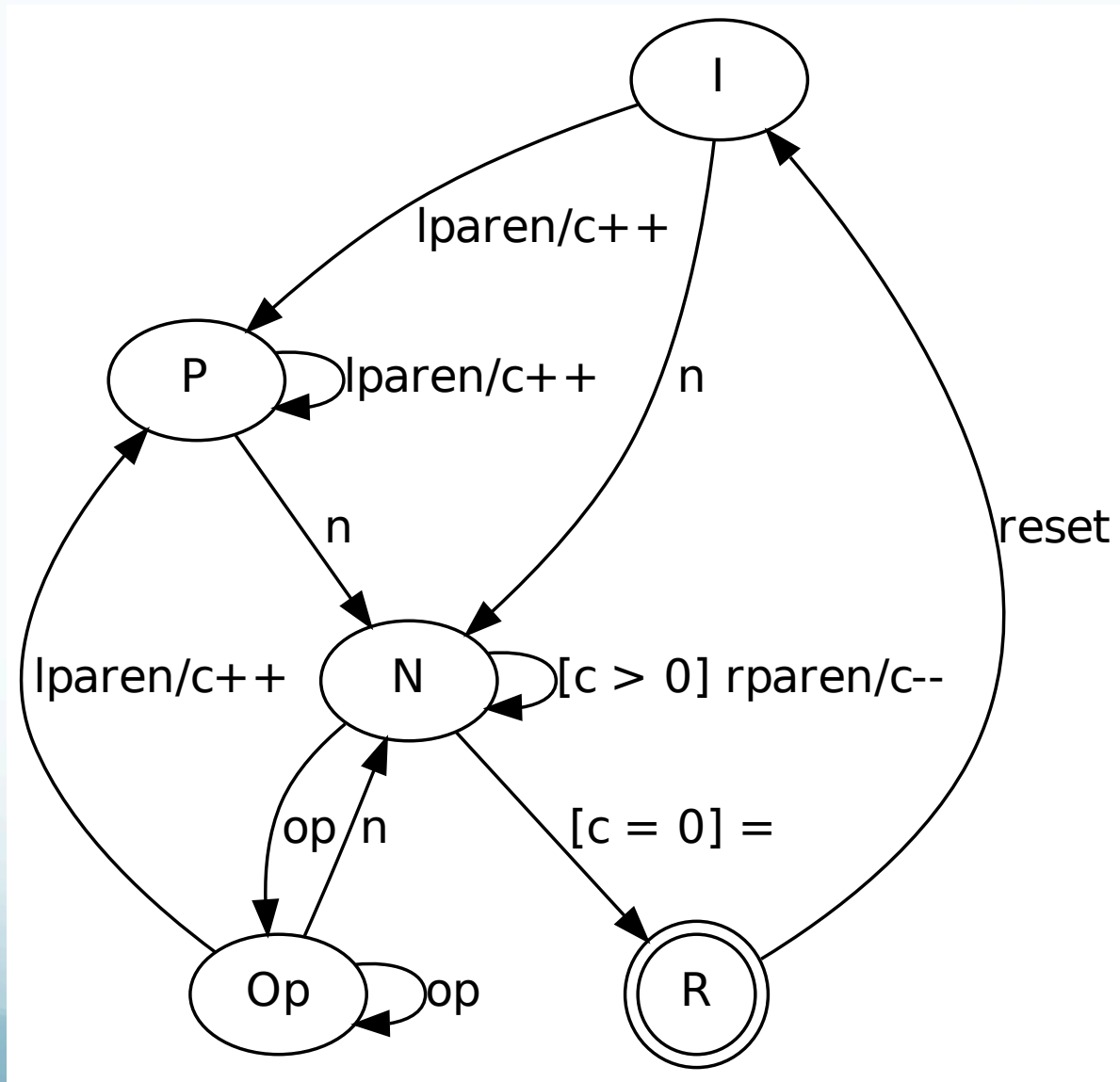
EFSM for Calculator (v.1)



EFSM for Calculator (v.2)

- Modify the previous EFSM to allow any number of operators between two operands
- The last operator is the one being considered, all the others being discarded

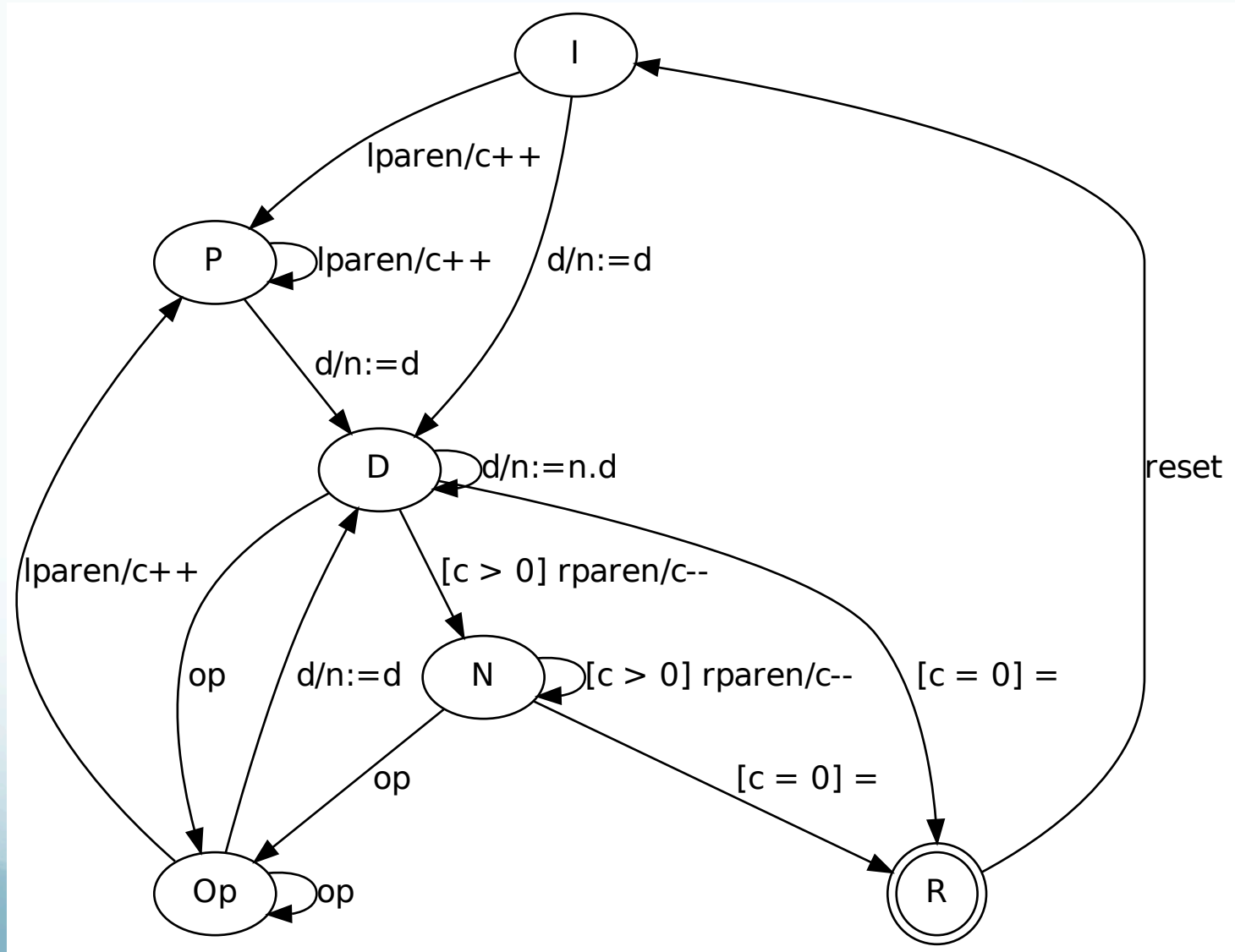
EFSM for Calculator (v.2)



EFSM for Calculator (v.3)

- Modify the previous calculator by replacing “full integers” by entering digit by digit
- The EFSM should handle digits individually to “build” the integer

EFSM for Calculator (v.3)



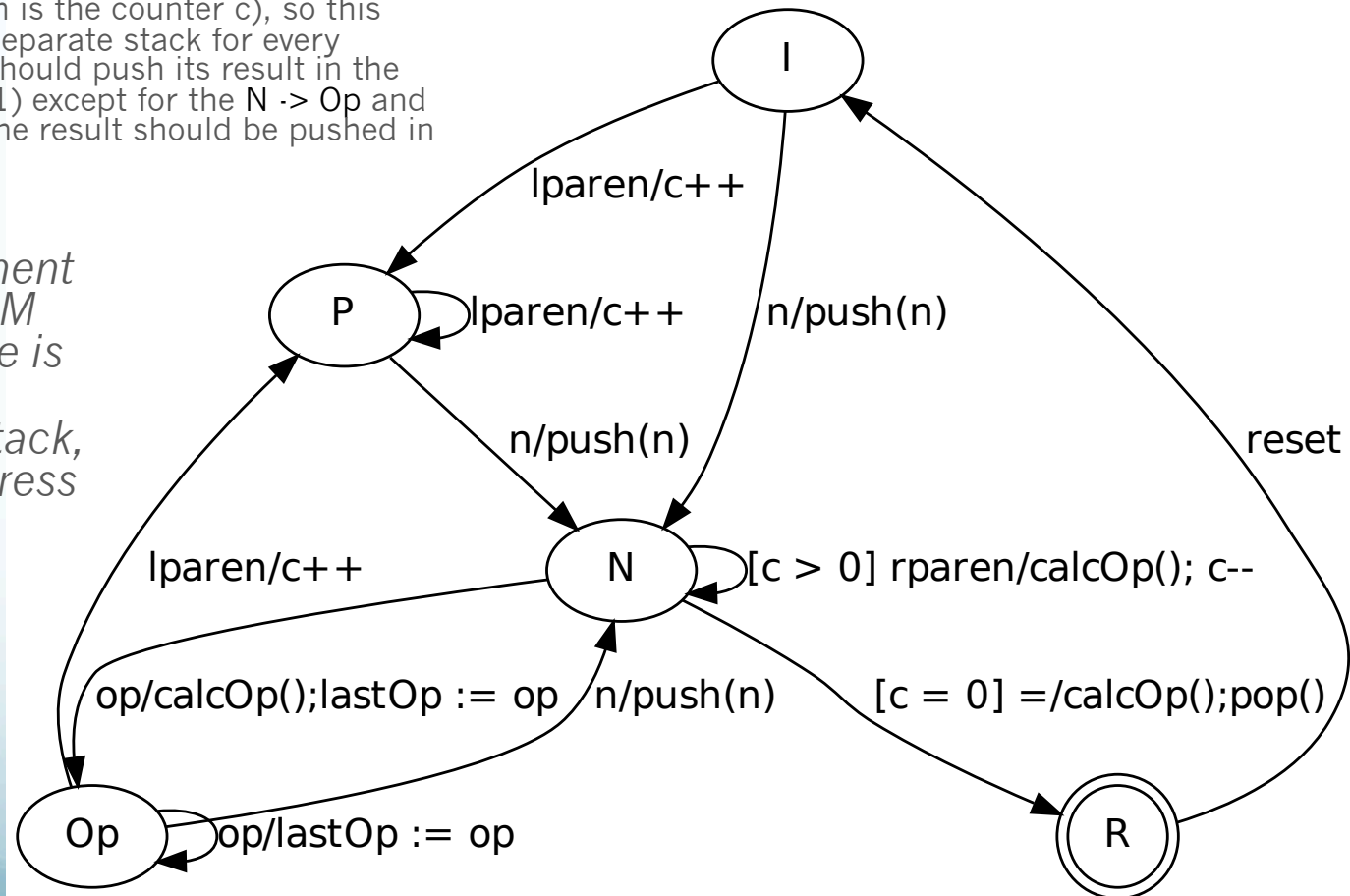
EFSM for Calculator (v.4)

- Write a more concrete EFSM expressing more operational properties so the evaluation of expressions are done more explicitly
- You should be able to check for division by zero
- Hint: You might use a stack to store operands and to store partial results

EFSM for Calculator (v.4) - Sketch

- Operands are pushed into a stack as they are read
- The 'current' operator is stored in a variable `lastOp`
- The operation `calcOp` pops two elements off the stack and performs the operation in `lastOp`
- Both `push` and `calcOp` need to be sensitive to the current nesting level (which is the counter `c`), so this implies we should keep a separate stack for every nesting level, and `calcOp` should push its result in the stack of the outer level (`c-1`) except for the `N -> Op` and `N -> R` transitions, where the result should be pushed in the current stack

Remark: *In the assignment you need a different EFSM (The solution shown here is very much linked to an implementation using stack, and doesn't explicit address division by zero)*



Making your tests executable

- Usually tests extracted from an (E)FSM are quite **abstract** -> need to make them executable
 - The API of the model doesn't match the API of the SUT
- Some common **abstractions** make **difficult** such match
 - Model one aspect of SUT, not whole behavior
 - Omit inputs and outputs which are not relevant
 - Simplify complex data structures
 - Assume SUT is in the correct state for the test
 - Define one model action as representing a sequence of SUT actions
- We must initialize the SUT, add missing details and fix mismatches between the APIs

This **concretization** phase may take as much time as modeling!

How to Concretize Abstract Tests

- To check SUT outputs we must either:
 - Transform the expected outputs from the model into concrete values
 - Get concrete outputs from the SUT and transform them into abstract values at the model

Some issues:

- Objects in SUT -> must keep track of identity (not only values)
- Need to maintain a map between abstract and concrete objects
 - Each time model creates a new abstract value A -> SUT creates a concrete object C (add pair (A,C) to the map table)
- Different approaches to do so...

How to Concretize Abstract Tests

- **Adaptation**: Write a wrapper (**adaptor**) around the SUT to provide a more abstract view of SUT
- **Transformation**: Transform abstract tests into concrete test scripts

The Adaptation Approach

- The **adaptor** code act as an interpreter for abstract operation calls of model, executing them in SUT (on-the-fly while abstract tests are generated)

Adaptors responsible for:

- **Setup**: configuring and initializing the SUT
- **Concretization**: translate model abstract operation call (and inputs) into SUT concrete calls (and inputs)
- **Abstraction**: translate back concrete results into abstract values to the model
- **Teardown**: shut down SUT at end of each test suite, to prepare for next test suite

The Transformation Approach

- **Test scripts** are produced in the **transformation** approach to transform each abstract test into an executable one

What is needed:

- Setup and teardown code at the beginning and end of each test sequence
- A complex template: many SUT operations to implement 1 abstract operation; trap SUT exceptions to check whether expected or not, etc
- A mapping from each abstract value to a concrete one
- A complex test script with conditionals to check SUT outputs when non-determinism

Which Approach is Better?

- **Adaptation** better for **online testing**
 - Tightly integrated, two-way connection between MBT tool and SUT
- **Transformation** has the advantage of producing tests scripts in the same language (same naming, structure) as used in manual tests
 - Good for **offline testing** (less disruption)
- Good to combine both (**mixed**)
 - Abstract tests transformed into executable test scripts which call an adaptor layer to handle low-level SUT operations

Online Testing in ModelJUnit

Example: Set<String>

Implementation of Set<String>

- **StringSet.java**
 - A simple implementation of a set of strings
- **SimpleSet.java**
 - A simplified model of a set of elements
 - Only the model (no adapter): could be used to generate offline tests
 - The model assumes a set with maximum two elements
- **SimpleSetWithAdaptor.java**
 - Like SimpleSet but with adaptor code
 - Allow to do online testing of a Set<String> implementation

Note: In the following slides we do not include the "import" packages - See the distribution for full code

Online Testing in ModelJUnit

Implementation: StringSet

```
public class StringSet extends AbstractSet<String>
{ private ArrayList<String> contents = new ArrayList<String>();
```

```
    @Override
    public Iterator<String> iterator()
    { return contents.iterator(); }
```

```
    @Override
    public int size()
    { return contents.size(); }
```

```
    @Override
    public boolean equals(Object arg0)
    { boolean same = false;
      if (arg0 instanceof Set) {
        Set<String> other = (Set<String>) arg0;
        same = size() == other.size();
        for (int i = contents.size() - 1; same && i >= 0; i--) {
          if (!other.contains(contents.get(i)))
            same = false; } }
      return same; }
```

```
    @Override
    public void clear()
    { contents.clear(); }
```

```
    @Override
    public boolean contains(Object arg0)
    { for (int i = contents.size() - 1; i >= 0; i--) {
      if (contents.get(i).equals(arg0))
        return true; } // return immediately
      return false; } // none match
```

```
    @Override
    public boolean isEmpty()
    { return contents.size() == 0; }
```

```
    @Override
    public boolean add(String e)
    { if (e == null) {
      throw new NullPointerException(); }
      if (contents.contains(e)) {
        return false; }
      else {
        return contents.add(e); } } // always adds to end
```

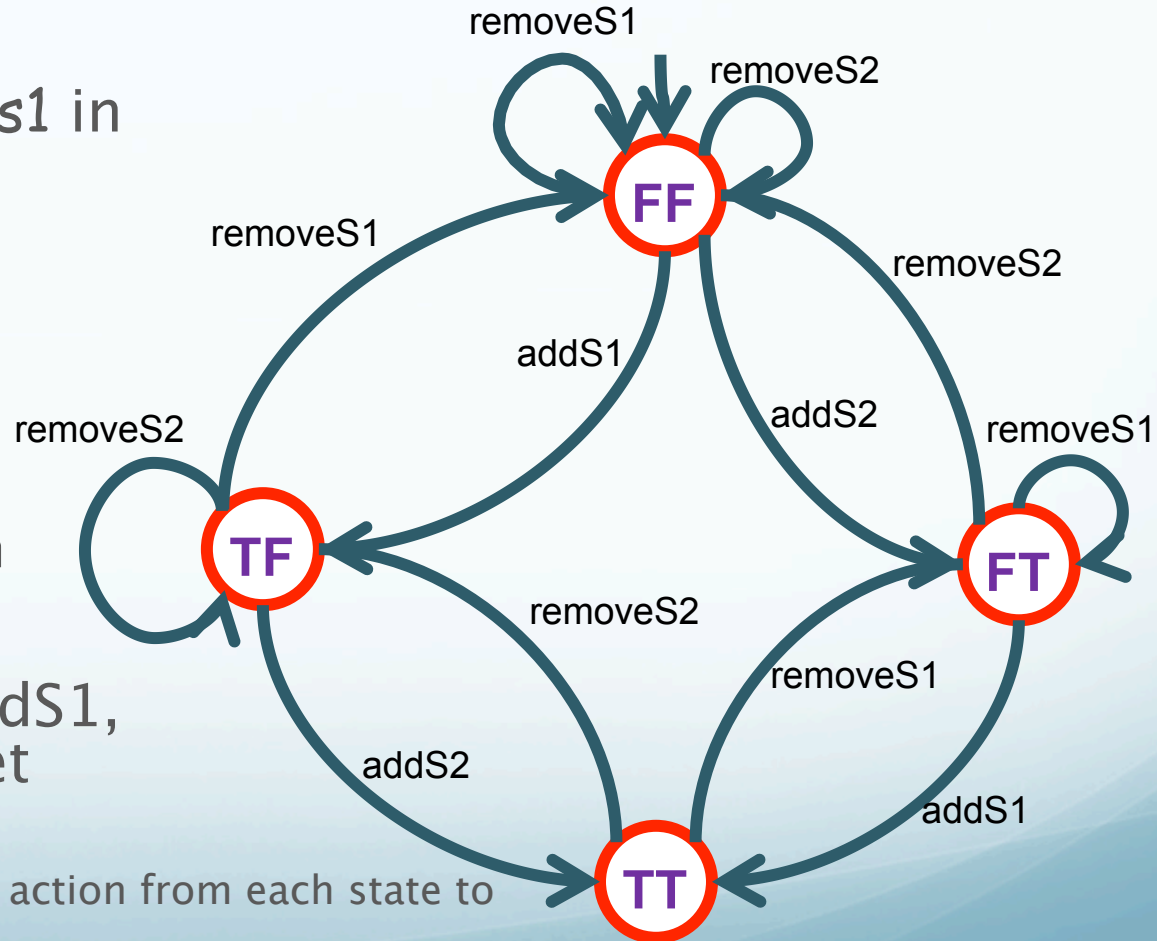
```
    @Override
    public boolean remove(Object o)
    { if (contents.isEmpty())
      return false;
      else
        return contents.remove(o); }
```

```
}
```

Online Testing in ModelJUnit

EFSM (2-elem set)

- Set: $S = \{s1, s2\}$
- Representation:
 $S = \langle x, y \rangle$, where $x=T$ if $s1$ in S and $y=T$ if $s2$ in S
- 4 states:
 - FF \rightarrow S is empty
 - FT \rightarrow S contains $s2$
 - TF \rightarrow S contains $s1$
 - TT \rightarrow S contains both $s1$ and $s2$
- Actions: removeS1, addS1, removeS2, addS2, reset



Note: we have not added the "reset" action from each state to state FF
Also, loops with "addS1" (in TF and TT), and "addS2" (in FT and TT) are missing

Online Testing in ModelJUnit

EFSM: SimpleSet

- So, in the **ModelJUnit** implementation of the set, instead of changing state explicitly, actions simply states how the "internal" variables change
 - **addS1()** -> is applicable only from a state where *s1* becomes true
 - **removeS1()** -> is only enabled from a state where after applying the action *s1* becomes false

Online Testing in ModelJUnit

EFSM: SimpleSet

```
public class SimpleSet implements FsmModel  
{ protected boolean s1, s2;
```

```
public Object getState()  
{ return (s1 ? "T" : "F") + (s2 ? "T" : "F"); }
```

```
public void reset(boolean testing)  
{ s1 = false; s2 = false; }
```

```
@Action public void addS1() {s1 = true;}
```

```
@Action public void addS2() {s2 = true;}
```

```
@Action public void removeS1() {s1 = false;}
```

```
@Action public void removeS2() {s2 = false;}
```

```
public static void main(String[] args)  
{ Tester tester = new GreedyTester(new SimpleSet());  
  tester.addListener(new VerboseListener());  
  tester.generate(100); }  
}
```

4 states: TT,
TF, FT, FF

reset transition
from all states
to FF

Define action to add
elem S1 to set:
from any state to
the state TX

Define action to
remove elem S1:
from any state to
the state FX

Example to
generate
tests from
the model

Online Testing in ModelJUnit

EFSM with Adaptor: SimpleSetWithAdaptor

```
public class SimpleSetWithAdaptor implements FsmModel
{
    protected Set<String> sut_;
    protected boolean s1, s2;

    protected String str1 = "some string";
    protected String str2 = ""; // empty string

    public SimpleSetWithAdaptor()
    { sut_ = new StringSet(); }

    public Object getState()
    { return (s1 ? "T" : "F") + (s2 ? "T" : "F"); }

    public void reset(boolean testing)
    { s1 = false;
      s2 = false;
      sut_.clear(); }

    @Action public void addS1()
    { s1 = true;
      sut_.add(str1);
      checkSUT(); }
```

Test data for the SUT

Tests a StringSet implementation (sut_)

Concrete operation in SUT for the abstract (EFSM) operation "reset"

Concrete operation in SUT for the abstract (EFSM) operation "addS1"

Check SUT in right state

Online Testing in ModelJUnit

EFSM with Adaptor: SimpleSetWithAdaptor

```
@Action public void addS2()  
{ Assert.assertEquals(!s2, sut_.add(str2)); //sut_.add(str2);  
s2 = true;  
checkSUT(); }  
  
@Action public void removeS1()  
{ s1 = false;  
sut_.remove(str1);  
checkSUT(); }  
  
@Action public void removeS2()  
{ Assert.assertEquals(s2, sut_.remove(str2)); //sut_.remove(str2);  
s2 = false;  
checkSUT(); }  
  
protected void checkSUT()  
{ int size = (s1 ? 1 : 0) + (s2 ? 1 : 0);  
Assert.assertEquals(size, sut_.size());  
Assert.assertEquals(s1, sut_.contains(str1));  
Assert.assertEquals(s2, sut_.contains(str2));  
Assert.assertEquals(!s1 && !s2, sut_.isEmpty());  
Assert.assertEquals(!s1 && s2, sut_.equals(Collections.singleton(str2))); }  
  
public static void main(String[] args)  
{ Set<String> sut = new StringSetBuggy(); // StringSetBuggy();  
Tester tester = new GreedyTester(new SimpleSetWithAdaptor(sut));  
tester.addListener(new VerboseListener());  
tester.addCoverageMetric(new TransitionCoverage());  
tester.generate(50);  
tester.printCoverage(); } }
```

Concrete operation in SUT for the abstract (EFSM) operation "removeS1"

How to test the result of sut_.add(.) – (In EFSM state whether s2 is false -> can call add(.) in implementation)

Check SUT in expected state

Check size of model and implementaion is the same

If EFSM in state where s2=T, then implement. should be in state where str2 is in the set

Example of generating tests from this model

Online Testing in ModelJUnit

Additional Remarks

- ModelJUnit, an iterative process:

getstate() ->
evaluate guard ->
execute action ->
update internal state ->...
- At each moment it is possible to relate with the SUT and check its state through the adaptor
- You can add code to measure coverage, traverse the model using specific algorithms, etc
- The code is automatically added when using the "Test Configuration" in ModelJUnit
- In some applications you have to modify the code too (not in the StringSet example)

References

- M. Utting and B. Legeard, *Practical Model-Based Testing*. Elsevier - Morgan Kaufmann Publishers, 2007
 - Sections 5.3 and 8.1

About next lectures...

- Only one more “theoretical” talk on **Mon Apr 27 (10:15-12:00)**: QuickCheck (by Koen Claessen)
- **Mon May 11 (10:15-12:00)**: Guest lecture on **Runtime Verification** (by **Gordon Pace**, Univ. of Malta)
- **Wed May 13 (10:15-12:00)**: Guest lecture on **Behavioural-Driven Development** (by **Pavel Rabetski**, Senior Software Engineer at Volvo Telematics Dept.)
- 4 tutorials: tools for drawing EFSMs, modeling, ModelJUnit, and QuickCheck
- . On **May 20**, there will be an experiment for testing - More information to come

IMPORTANT: The rest of the dates are to be dedicated to work on your mini-projects