Model-Based Testing

(DIT848 / DAT260)
Spring 2012

Lecture 10
EFSMs and Executable Tests
(in ModelJUnit)

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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

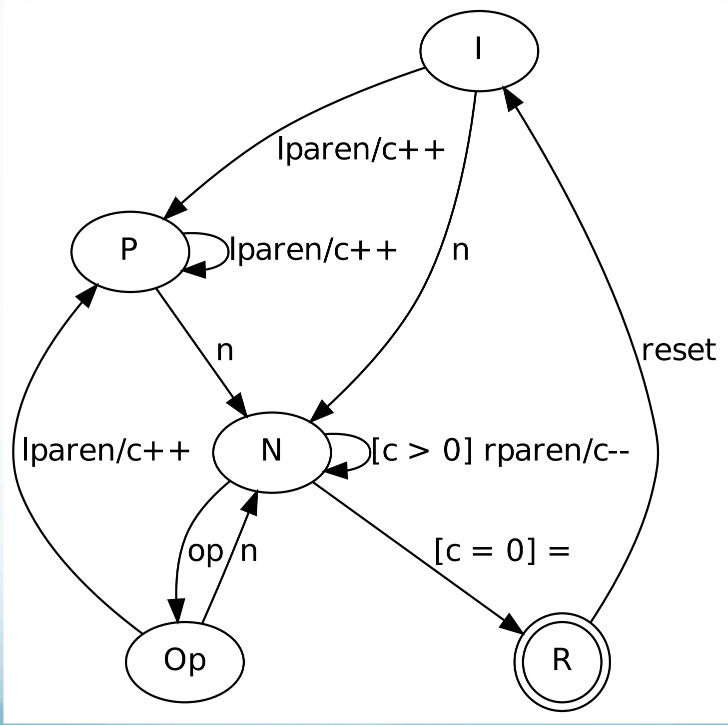
- Interactive exercises on building an EFSM
  - Partial solution to the 1st part of Assignment 5
- Executable tests
- Online testing with ModelJUnit

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)

Groups 2-5 persons: 15 min

EFSM for Calculator (v.1)

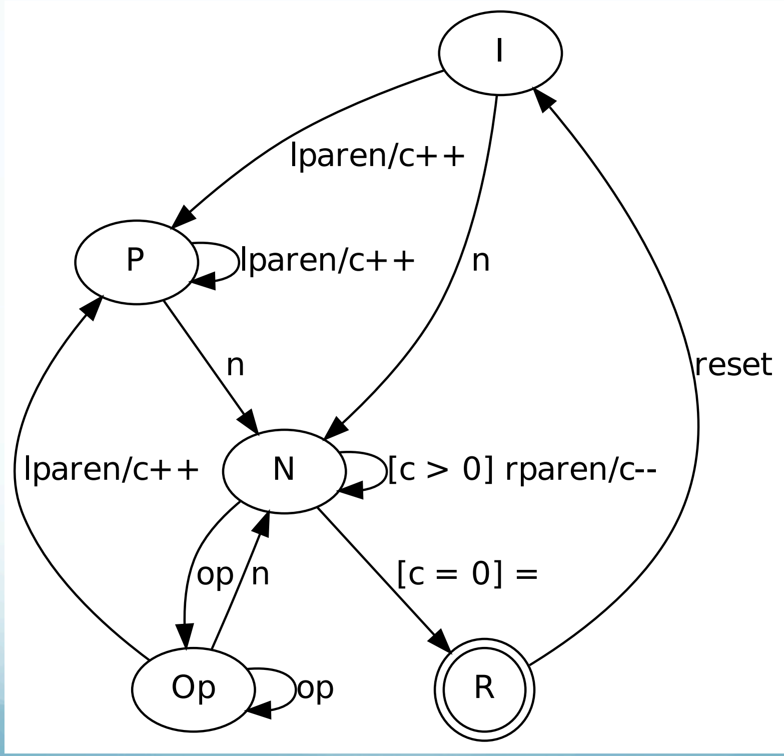


EFSM for Calculator (v.2)

- 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

Groups 2-5 persons: 5 min

EFSM for Calculator (v.2)

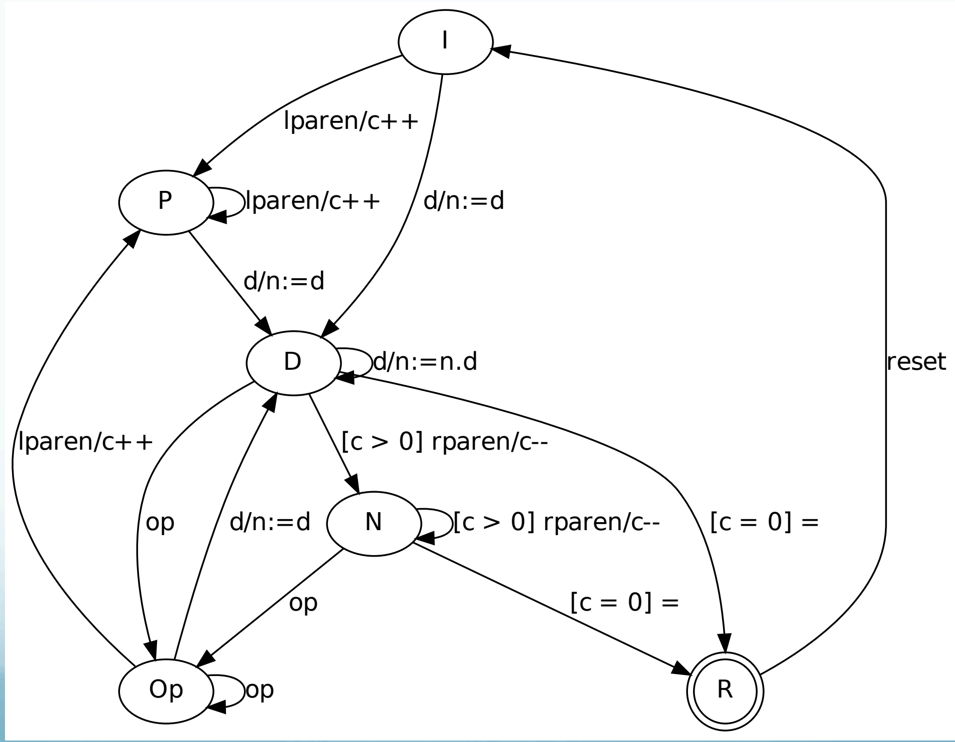


EFSM for Calculator (v.3)

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

Groups 2-5 persons: 10 min

EFSM for Calculator (v.3)



EFSM for Calculator (v.4)

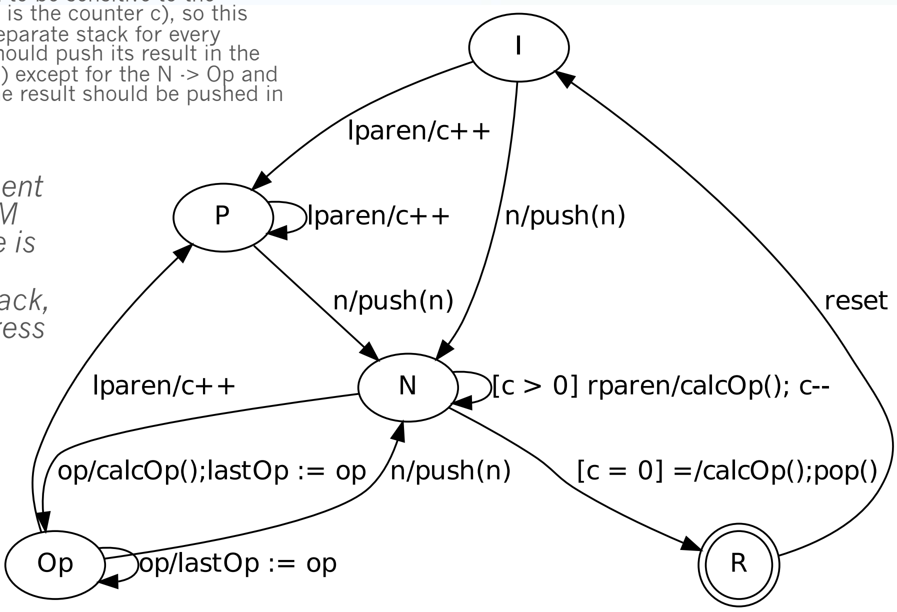
- Write a more concrete EFSM expressing more operational properties so the evaluation of expressions are done more explicitly
- You should be able to check for division by zero
  - Hint: You might use a stack to store operands and to store partial results

Groups 2-5 persons: 15 min

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 making **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 action as representing a sequence of SUT actions
- We must initialize the SUT, add missing details and fix mistmatches between the APIs

This concretization phase may take as much time as modeling!

How to Concretize Abstract Tests

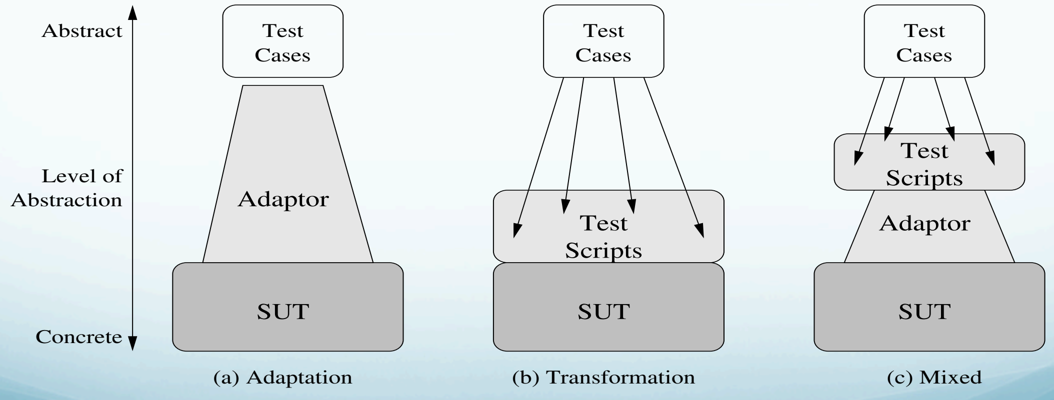
- We must either:
  - Transform the expected outputs from the model into concrete values
  - Get concrete outputs from the SUT and transform them into abstract values at the model

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



Utting & Legeard book: Fig. 8.1 pp.285

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

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 exceptions, 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)
- For offline testing good to combine both (*mixed*)
  - Abstract tests transformed into executable test scripts which call an adapter layer to handle low-level SUT operations

Online Testing in ModelJUnit Example: Set<String>

Implementation of Set<String> (see assignment 4)

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

- StringSet.java
  - A simple implementation of a set of strings
- SimpleSet.java
  - A simplified model of a set of elements
  - Only the model (no adaptor): 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

* Examples and source codes from the ModelJUnit distribution (under subdirectory "examples2.0")- Copyright (C) 2007 Mark Utting

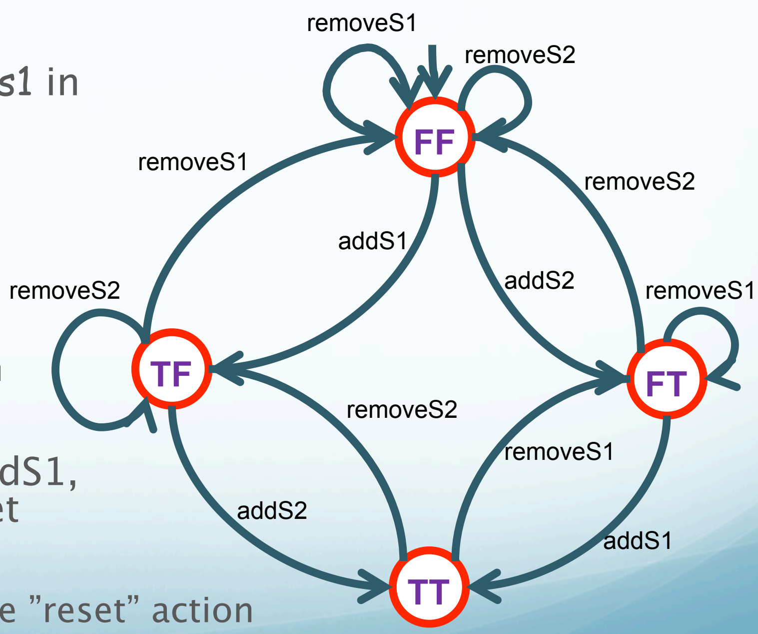
Online Testing in ModelJUnit Implementation: StringSet

```
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); }
}
```

* Examples and source codes from the ModelJUnit distribution (under subdirectory "examples2.0")- Copyright (C) 2007 Mark Utting

Online Testing in ModelJUnit EFSM (2-elem set)

- Set: S = {s1, s2}
- Representation: S = <x,y>, where x=T if s1 in S and y=T if s2 in S
- 4 states:
  - FF -> S is empty
  - FT -> S contains s2
  - TF -> S contains s1
  - TT -> 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" ("addS2") 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 enable 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

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(); } }
```

How to test the result of sut_.add(...)

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

Check SUT in expected state

Check size of model and implementaion is the the same

If EFSM in state where s2=T, then impl. 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)

* Examples and source codes from the ModelJUnit distribution (under subdirectory "examples2.0")- Copyright (C) 2007 Mark Utting

Assignment 5

You will have to:

- Define the EFSM of a complex calculator
- Encode it in ModelJUnit
- Write an adaptor
- Execute online tests to find errors, using some of ModelJUnit traversal algorithms
  - Define (and measure) state and transition coverage

References

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