Input Data Generation for Model-based Testing

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Outline

- Background
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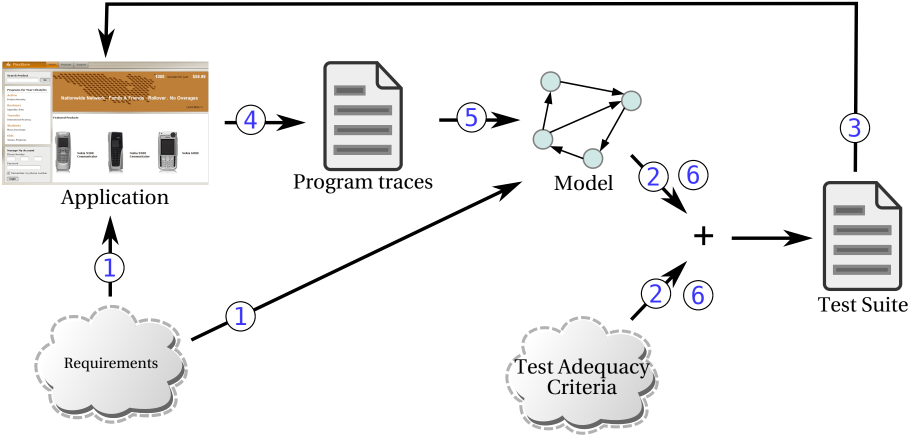
  - Test Adequacy Criteria
- Proposed Approach
  - Working example
  - Input Data Generation Problem
  - Intuition behind the solution
  - the Tool
  - a Case study
- Conclusions

Model-based Testing - the Process



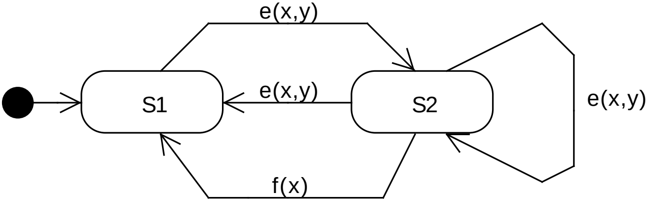
Model-based Testing - the Model

Given that:

- SUT' state is observable by "inspector" messages
- SUT' state changes due to "mutator" messages
- observable states are abstracted collapsing "equivalent" ones

SUT is modeled by a Finite State Machine (FSM):

- with parametrized events, e.g. $e(x, y)$
  - method calls, http requests, etc.
- non-deterministic



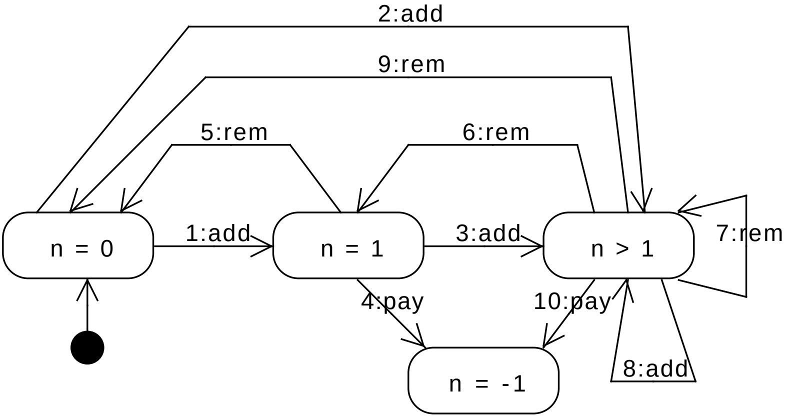
Test Adequacy Criteria

- "good" test cases:
  - can hardly be defined a-priori
  - informally are effective, cheap, helpful to identify the underlying fault
- test adequacy criteria:
  - are a means to concretely specify the extent to which a test suite has to exercise a SUT
- currently, well-accepted criteria are:
  - **all transitions coverage**: [fsm] every transition in a FSM has to be traversed by at least a test case
  - **all branches coverage**: [source code] every branch in a program's CFG has to be executed by at least a test case

Subject Under Test Example

```
package cart;

public class Cart {

    public Cart() { ... }

    public void add(int c) { ... }

    public void rem(int c) { ... }

    public void pay() { ... }

    public int n() { ... }

}
```

SUT Model



- actual Cart's state is abstracted with 4 states
- transitions are triggered by events: `add(int c)`, `rem(int c)`, `pay()`

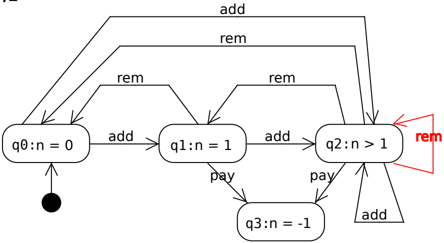
FSM specification

```
mutators {
    a := add(int);
    r := rem(int);
    p := pay();
}

inspectors {
    int n:=n();
}

states {
    n0 [initial] { n == 0; } ;
    n1 { n == 1; } ;
    n2 { n > 1; } ;
    n3 { n == -1; } ;
}
```

```
transitions {
    n0 -> n1 { a; } ;
    n0 -> n2 { a; } ;

    n1 -> n0 { r; } ;
    n1 -> n2 { a; } ;
    n1 -> n3 { p; } ;

    n2 -> n2 { a; } ;
    n2 -> n2 { r; } ;
    n2 -> n3 { p; } ;
    n2 -> n1 { r; } ;
    n2 -> n0 { r; } ;
}
```

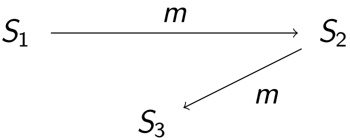
Input Data Generation Problem (Example)

- Test Requirement:
  - traverse $rem(n) : q_2 \longrightarrow q_2$
- Problem:
  - devise a path that reaches state q_2
  - find out the proper inputs:
    - to reach q_2 and then
    - to traverse $rem : q_2 \longrightarrow q_2$



Intuition behind the proposed approach

Observation: if the SUT logic was implemented following a typical FSM design pattern ...

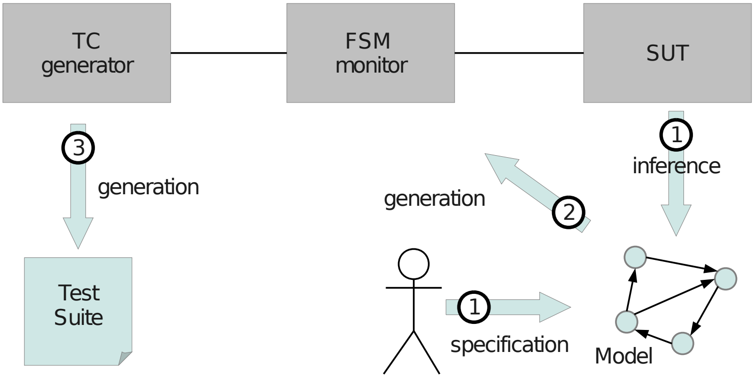



```
// pseudo-code to handle
// transitions triggered by m

if (s==1)
    s=2 // S_1 -> S_2
elseif (s==2)
    s=3 // S_2 -> S_3
else
  throw unexpected
```

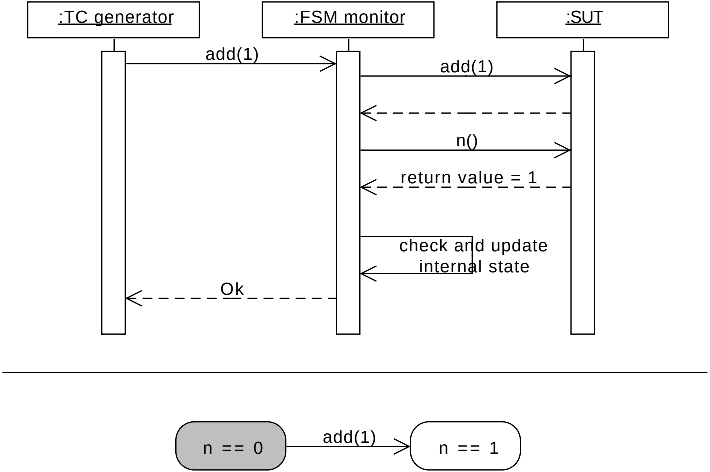
... CFG branches corresponds to FSM transitions.

FSM Monitor Generation

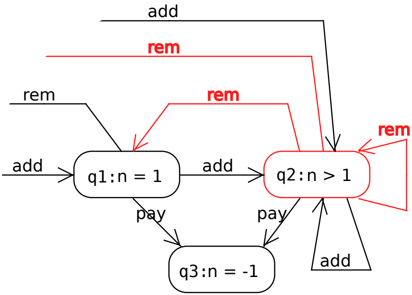
- Introduce a component which encodes the FSM logic in its branches, a sort of “man-in-the-middle”, so that exploring its branches means exploring SUT transitions.



FSM Monitor Generation



FSM Monitor Generation




```
void rem(int n) {
  sut.rem(n);
  switch (s_state) {

  case 2:
    if ( n > 1 ) {
      s_state = 2;
    } else if ( n == 1 ) {
      s_state = 1;
    } else if ( n == 0 ) {
      s_state = 0;
    } else {
      throw new UnderSpecEx(...);
    }
    break;

  case 1:
    ...
}
```

FSM Monitor Generation

- **observation:** From the FSM, we can build a class A so that:

if the SUT is compliant with FSM, then

All Transitions Criterion for FSM is satisfied
iff
All $\overset{NonError}{\curlyvee}$ Branches Criterion for A is satisfied

- **theoretical result**: it's true!
- **COTS are available**: we can use an already available TC generator for branch coverage (e.g. **Evosuite**)
- **generator implementation**: template-based ⇒
  - highly configurable
  - different implementation styles can be supported
  - graphical representations can be produced with proper templates

TC Generator - Evosuite

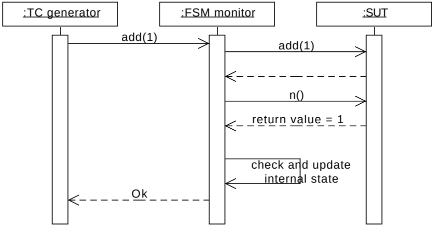
Evosuite[1] is a search-based test suite generator for Java

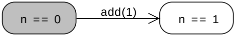
- based on an evolutionary approach, i.e. it mimics natural evolution to optimize branch coverage:
  - candidate solutions in the search space are modeled by chromosomes
  - good candidate solutions have high branch coverage level
  - chromosomes of "best" individuals are combined by cross-over
  - some chromosomes are mutated to maintain diversity and to introduce new alleles
- uses whole test suite generation strategy:
  each chromosome encodes a whole test suite

[1] http://www.evosuite.org/ - G. Fraser and A. Arcuri

Detecting Diverging Behavior - 1

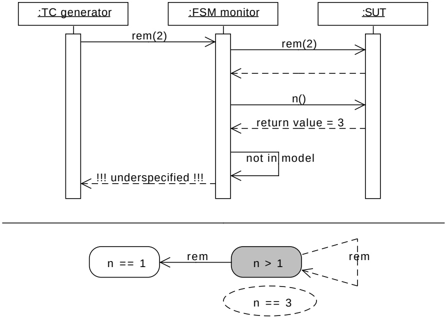
SUT	Model	Out	Effect
Ok, q'	$q \xrightarrow{m} q'$	Ok	invocation accepted
Ok, q'	$q' \notin T(q, m)$	Undersp. Exc.	TC discarded
Error	$m \in Out(q)$	Infeasible Exc.	TC discarded
-	$m \notin Out(q)$	Infeasible Exc.	TC discarded





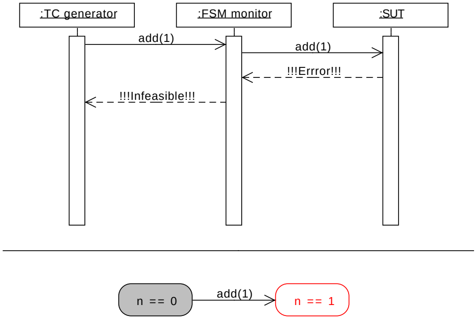
Detecting Diverging Behavior - 2

SUT	**Model**	**Out**	**Effect**
Ok, q'	$q \xrightarrow{m} q'$	Ok	invocation accepted
Ok, q'	$q' \notin T(q, m)$	Undersp. Exc.	TC discarded
Error	$m \in Out(q)$	Infeasible Exc.	TC discarded
-	$m \notin Out(q)$	Infeasible Exc.	TC discarded



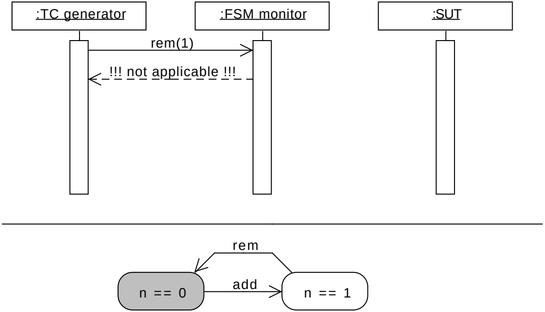
Detecting Diverging Behavior - 3

SUT	Model	Out	Effect
Ok, q'	$q \xrightarrow{m} q'$	Ok	invocation accepted
Ok, q'	$q' \notin T(q, m)$	Undersp. Exc.	TC discarded
Error	$m \in Out(q)$	Infeasible Exc.	TC discarded
-	$m \notin Out(q)$	Infeasible Exc.	TC discarded



Detecting Diverging Behavior - 4

SUT	Model	Out	Effect
Ok, q'	$q \xrightarrow{m} q'$	Ok	invocation accepted
Ok, q'	$q' \notin T(q, m)$	Undersp. Exc.	TC discarded
Error	$m \in Out(q)$	Infeasible Exc.	TC discarded
-	$m \notin Out(q)$	Infeasible Exc.	TC discarded



Test Suite

```
//Test case number: 0
   testCart0.add(1);
   testCart0.add(1);
   testCart0.add(1);

//Test case number: 1
   testCart0.add(2);
   testCart0.pay();

//Test case number: 2
   testCart0.add(11);
   testCart0.rem(11);

//Test case number: 3
   testCart0.add(1);
   testCart0.rem(1);

//Test case number: 4
   testCart0.add(1734);
   testCart0.rem(1);

//Test case number: 5
   testCart0.add(2);
   testCart0.rem(1);

//Test case number: 6
   testCart0.add(1);
   testCart0.pay();
```

- Note: test cases are small thanks to Evosuite's minimization algorithm.

Flexstore

Search Product
Go
Programs for Your Lifestyles
Active
Product Warranty
Business
Upgrades, Data
Traveler
International Roaming
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Password
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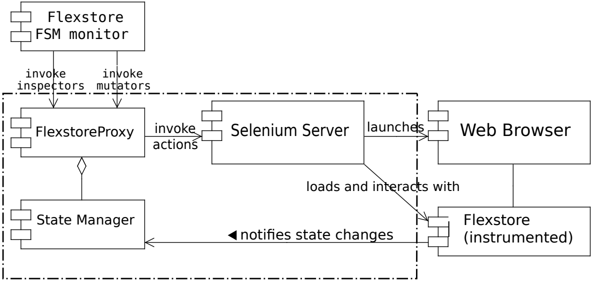

Flexstore FSM monitor
invoke inspectors
invoke mutators
FlexstoreProxy
invoke actions
Selenium Server
launches
Web Browser
loads and interacts with
State Manager
notifies state changes
Flexstore (instrumented)

Conclusions

- a method to resolve the input data generation problem was proposed
- it is base on the idea that "all transition coverage" criterion can be transformed into "all branches coverage" criterion for which already exists good solutions (e.g. Evosuite)
- the transformation was formally proved correct (not shown)
- the method was successfully applied to a real application

That's all

Thanks for your kindly attention,
any question?