St. Petersburg State University of Information Technologies, Mechanics and Optics

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A GA-based approach for test generation for automata-based programs

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Agenda

- **Automata-based approach and problem of the quality assurance**
- Developing and testing automata-program:
  1. Creating model and formalizing requirements
  2. Defining test scenarios
  3. Creating executable tests
  4. Running tests
- Summary

Automata-based approach

- Automata-based program consists of:
  - model, a formal automata (FSM)
  - control objects
- Model defines behavior of the system
- Control objects interact with environment (input/output)

Problem of quality assurance

- The problem is to check program against its specification requirements
- There are three parts of automata-program that could contain errors:
  - model
  - controlled objects
  - interaction of the automaton with its controlled objects
- There are ways to check automata-model (*Model Checking*), but they don’t work for controlled objects and system in whole

Proposed solution

- To use ***automata-tests*** to check the automata-based system in whole (model + controlled objects)
- Automata-test simulates inputs to the system and checks behavior of the system for this inputs
- Drawbacks of testing approach:
  - can not guarantee the correctness of a program
  - normally a labor intensive and very expensive task

Significance of the problem

- No approach or tools to test automata-programs
- Extended Finite State Machine (EFSM) related approaches don't support an interaction with controlled objects
- Traditional testing approaches can not be applied to automata-program as is:
  - all benefits of automata approach would be lost
  - metrics are not meaningful
- Testing is labor-intensive and requires automation tools

Steps to test an automata-program

1. Formalize natural language specification
2. Describe test cases
3. Create an executable test
4. Run tests and check implementation against its specification

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I. Formalize specification

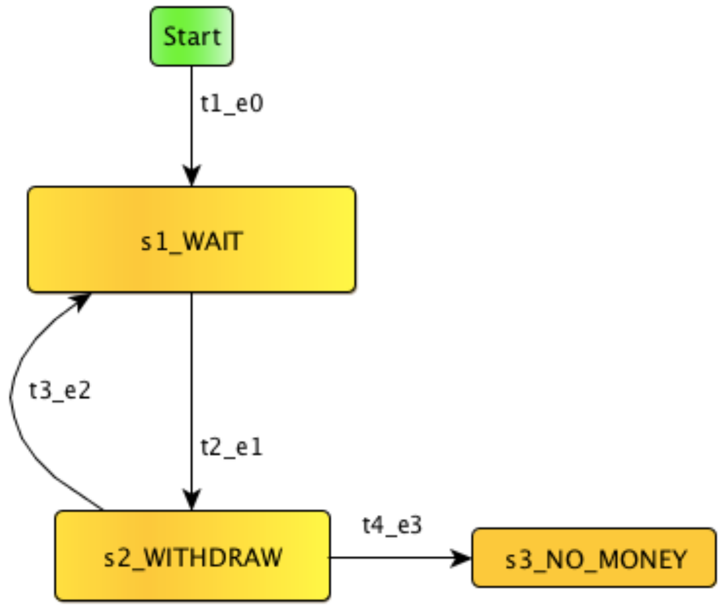
- Specification usually is described in natural language
- Example of ATM-like system:
  - system withdraws from an account
  - initially sum on account is more then 0 and less then 100000
  - user can withdraw infinitely while sum is positive
  - user enters amount to withdraw, more then 1 000 and less then 15 000
  - no more then 50 000 can be withdrawn during one day of operation
- Good only for manual testing

I. Groups of requirements

- Model's requirements:
  - system withdraws from an account
  - user can withdraw infinitely while sum is positive
  - no more then 50 000 can be withdrawn during one day of operation
- Control objects' requirements:
  - initially sum on account is more then 0 and less then 100000
  - user enters amount to withdraw, more then 1 000 and less then 15 000

I. Developing a model - FSM

- We define events:
  - e0 – initialized
  - e1 – user input
  - e2 – transaction complete
  - e3 – error



- A lot of logic is hidden in control objects' implementation

I. Covered requirements

- Model’s requirements:
  - system withdraws from an account
  - user can withdraw infinitely while sum is positive
  - no more then 50 000 can be withdrawn during one day of operation
- Control objects’ requirements:
  - initially sum on account is more then 0 and less then 100000
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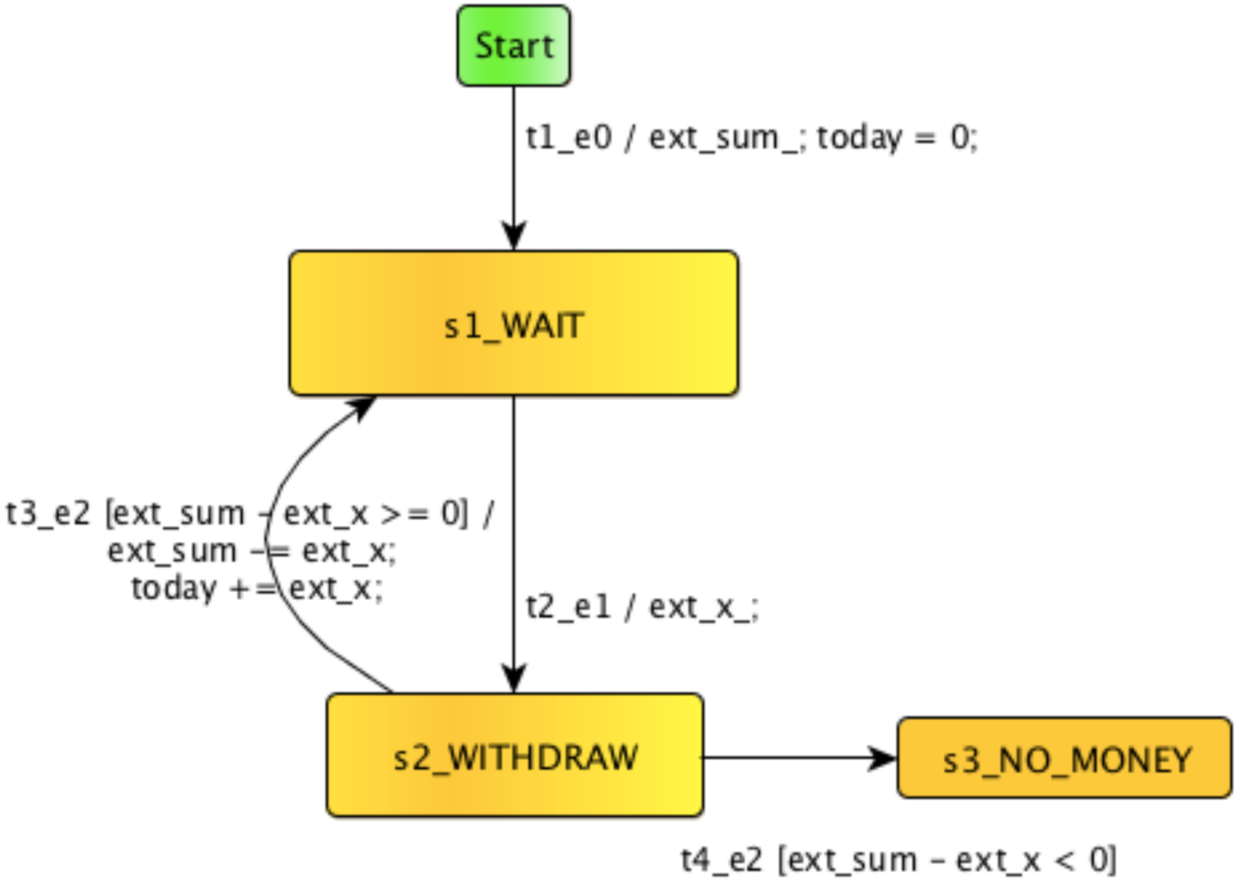
I. Developing a model - EFSM

- Extended Finite State Machine supports variables and suits for more complex models



I. Covered requirements

- Model's requirements:
  - system withdraws from an account
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I. More ways to describe requirements

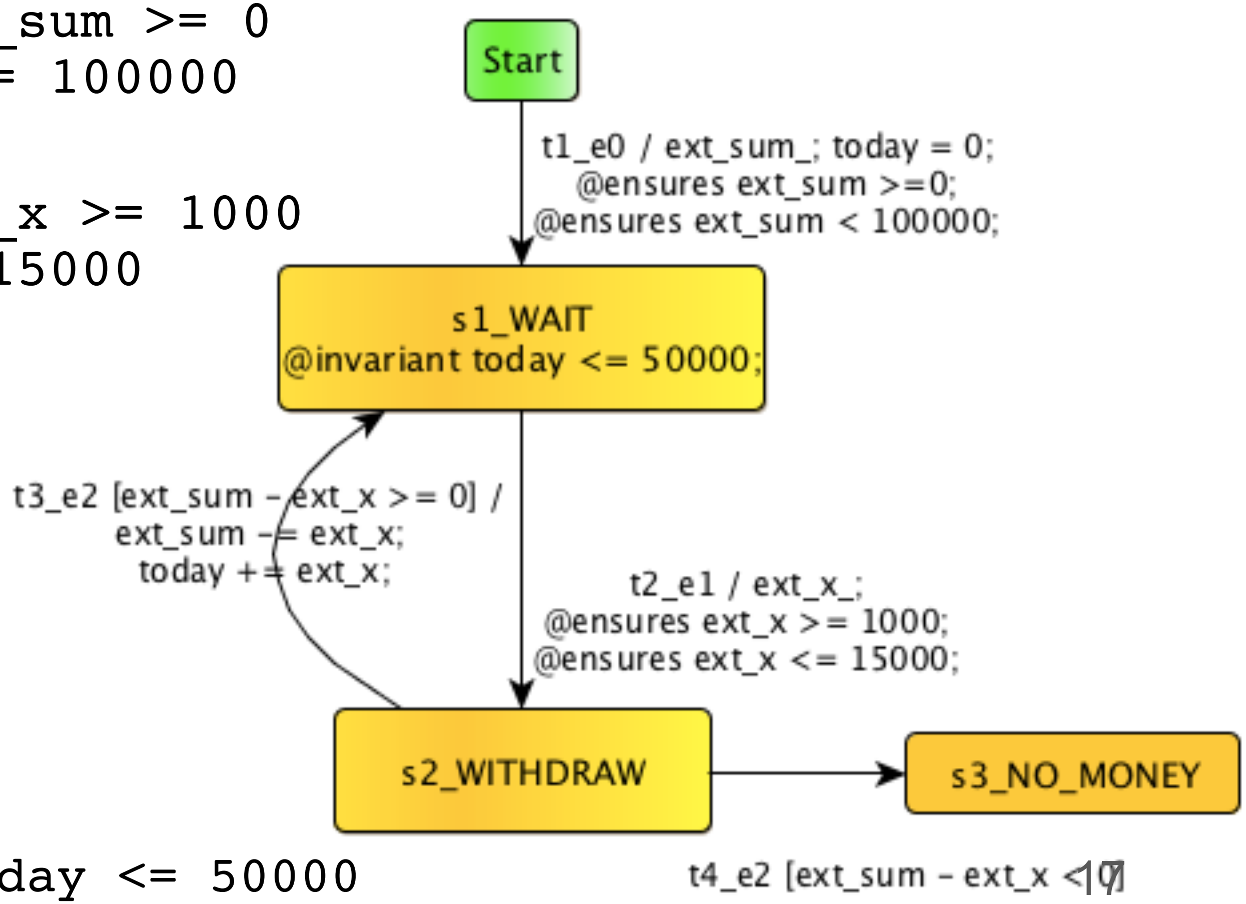
- Controlled objects contain some logic, as using EFSM is not always good:
  - too complex model
  - model’s requirements and control objects’ requirements would be mixed up
- Need to formalize requirements to check the model and controlled objects implementation
- Design by contract approach
  - preconditions, postconditions, invariants

I. Requirements as contracts

- Control object requirements can be added as pre- and postconditions of the transitions
- Model's requirements can be added as invariants to the states
- Java Modeling Language (JML) to write requirements
- Benefits of such approach:
  - model shows specification requirements
  - developer-friendly syntax

I. Developing a model – EFSM+JML

- Account:
  - `@ensures ext_sum >= 0 && ext_sum <= 100000`
- User input:
  - `@ensures ext_x >= 1000 && ext_x <= 15000`



- Model
  - `@invariant today <= 50000`

I. Covered requirements

EFSM

Contracts

Model's requirements:

- system withdraws from an account
- user can withdraw infinitely while sum is positive
- no more then 50 000 can be withdrawn during one day of operation

Control objects' requirements:

- initially sum on account is more then 0 and less then 100000
- user enters amount to withdraw, more then 1 000 and less then 15 000

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II. Defining test cases

- Convenient to describe test scenarios in natural language
- Let’s define formally test case as a sequence of transitions in the automaton
  - easy conversion to and from natural language
  - can be generated automatically
- Test scenario looks like:
  - `t1, t2, t4, t5, t2, t4, t5, t2, t4`

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III. Test scenario execution

- To execute the given path it's necessary:
  - provide events in the correct order
  - provide values for the external variables
- External variable values come from environment:
  - no access to environment on testing stage
  - automation is wanted
- It's a problem to guess these values:
  - fulfill all the transition guards
  - fulfill control objects' contracts

III. Guessing variable values

- Genetic algorithm can be applied
- Fitness function estimates how good is given set of values for the desired path:
  - successful steps
  - branch distance for failed steps
  - location of failed steps
- Values with zero fitness will make the test
- GA is applied to solve optimization problem

III. GA details

- Chromosome is a vector of variable values
  - `<x1, x2, …, xn>`
- One-point crossover operator

```
<x1, x2, x3, x4>                <x1, x2, x3, y4>
<y1, y2, y3, y4>   ------->     <y1, y2, y3, x4>
```

- Mutation – replace random variable with random number
- Fitness function
  - branch distance: $("A >= B") = \begin{cases} 0, A >= B \\ \hline |A - B|, A < B \end{cases}$
  - weighted sum, path $= \sum_{i=0..m-1} f_i * d_i$

III. Guessing values example (1)

- Example of test cases:
  - **Three times** withdrawal operation is successful, forth time there is not enough on the account
  - **Twenty times** withdrawal operation is successful
- Different variable values are required for these tests

III. Guessing values example (2)

- First test scenario transition path:
  - **`t1, t2, t3, t2, t3, t2, t3, t2, t4`**
- Five external variables are used:
  - **`ext_sum`** – initial value on the account;
  - **`ext_x1`** – first withdrawal;
  - **`ext_x2`** – second withdrawal;
  - **`ext_x3`** – third withdrawal;
  - **`ext_x4`** – failed to withdraw.
- Proof-of-concept tool accepts transition path and returns set of variables

III. Generating executable tests

- Automatically found values:
  - **`ext_sum = 15673`**;
  - **`ext_x1 = 4357; ext_x2 = 8023;`**
  - **`ext_x3 = 2162; ext_x4 = 9183;`**
- Executable test on Java can be created and run later
- Organizing big test suits are good for regression and stress testing

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IV. Running tests

- Behavior of the system need to be checked during the evaluation of the given path
- If JML contracts are defined for states on this path they would be checked at the runtime:
  - JML Runtime Assertion Checker can be used
- In the example **`@invariant today <= 50000`** will be checked after each transaction
- In case of failing the condition an exception will be raised

IV. Running tests

- Implicit requirements are always checked:
  - deadlocks
  - exception
  - execution time
  - etc.
- For real control objects contracts will be useful to reveal inadequate implementation

Values that fail requirements

- Fitness function may take into the account model's specification
- It will help to find values that fail requirements
- Examine steps of the given path sequentially:
  - try to fail at first step
  - fulfill first step and fail second
  - …
  - fulfill first *n-1* steps and fail n^{th} step

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Approach summary

1. Specification is formalized using EFSMs and JML contracts
2. Test scenarios are described as a transition path
3. GA-based tool is used to find variable values for given path and executable tests are generated
4. Tests are run automatically and JML requirements fulfillment is checked at the runtime

Thank you

- Questions & Answers

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