Formal Approaches for Testing against Non-deterministic Specifications & Related Complexity Issues

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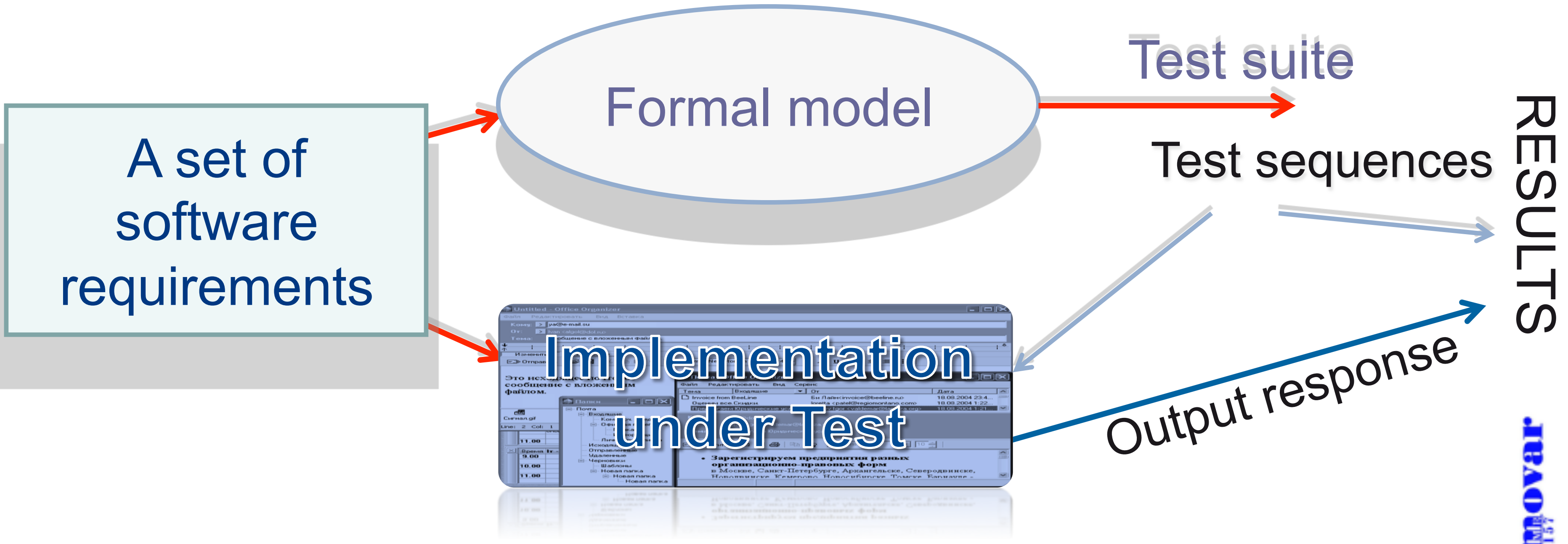
Motivation

- Every information system has software and hardware components (often from different providers)
- The quality of the corresponding components needs to be verified thoroughly
- Tests with guaranteed fault coverage can be derived only when addressing to formal models
- Guaranteed fault coverage requires lots of assumptions
- Testing should be scalable enough

$\Downarrow$

Novel testing approaches should be developed
Complexity should be estimated / decreased

Model based testing



Testing steps:

↓ deriving test sequences

↓ applying the test sequences against a given IUT

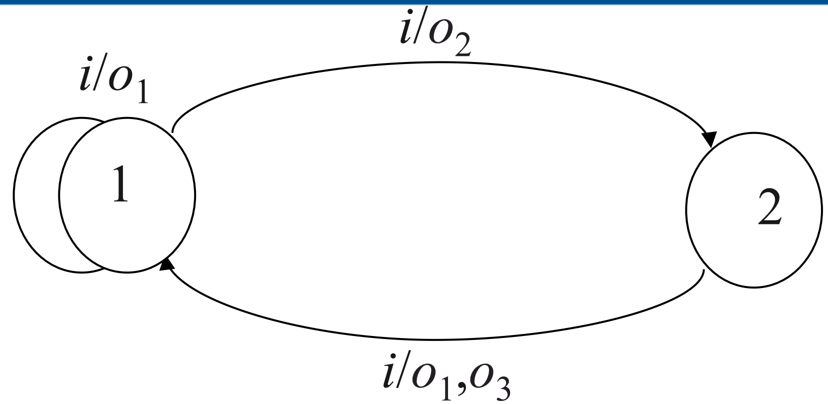
↓ drawing a conclusion about the correctness of the IUT

For reactive systems, Finite State Machines are widely used as Formal Models

Finite State Machine (FSM)

$\mathcal{S} = \langle S, I, O, h_S, S' \rangle$ is an FSM

- S is a finite set of states
  S' is a subset of initial states
- I and O are finite input and output alphabets
- $h_S \subseteq S \times I \times O \times S$ is a behavior relation



Can be

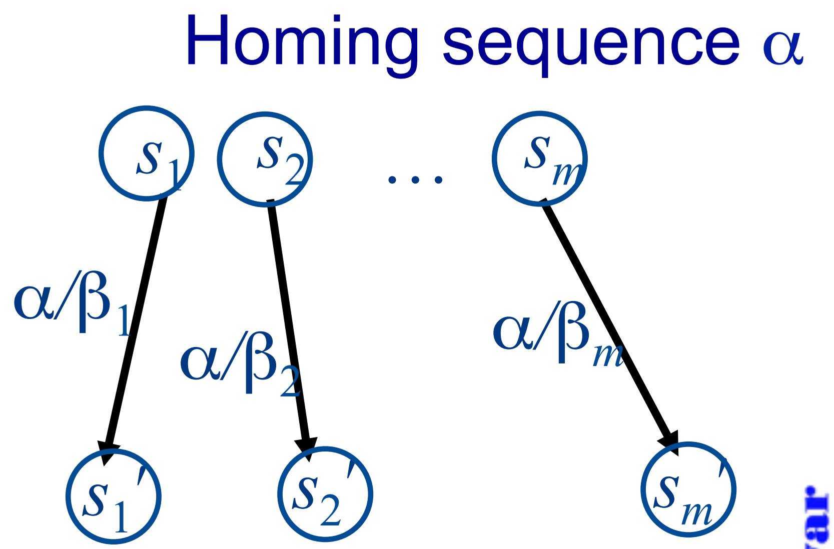
- *Complete* or *partial*
- *Deterministic* or not
- *Observable* or not
- ...

Telecommunication protocols can be highly non-deterministic, due to the optionality

Test suite derivation is based on the effective initial / final state identification

Homing sequence (HS)

- α allows to detect the final state of the machine after α is applied
- After applying α at state s_i and observing an output response β_i the final state s_i' becomes known



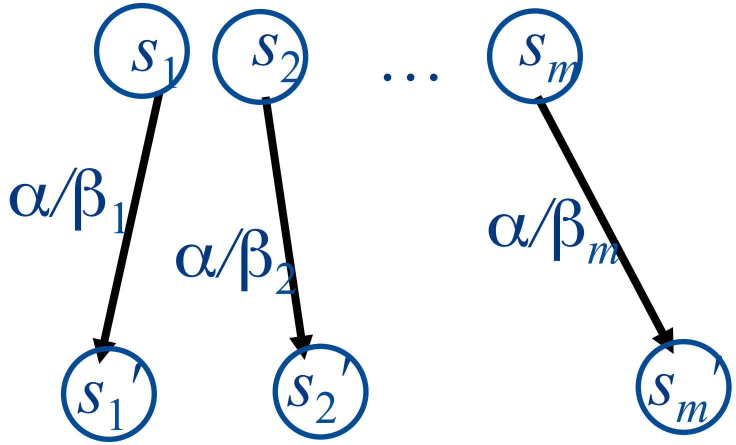
Applying α + observing $\beta_i \rightarrow$ drawing a conclusion about s_i'

- **We proposed methods for final state identification for partial and/or non-deterministic specifications [1]**
- **We also estimated the related complexity [2]**

Distinguishing sequence (DS)

- α allows to detect the initial state of the machine
- After applying α at state s_i and observing an output response β_i the initial state s_i becomes known

Distinguishing sequence α



$out(s_i, \alpha) \cap out(s_j, \alpha) = \varnothing$

- **We proposed methods for initial state identification for partial and non-observable specifications**
- **We also estimated the related complexity [3]**

Bad… very bad ‘news’

Most of the problems in the area of model based testing are NP/ PSPACE-complete

- **Checking the existence of a distinguishing sequence for complete deterministic FSMs is PSPACE-complete**
- **Learning a deterministic FSM under a given set of input/output sequences is NP-complete**

- **Checking the existence of a homing sequence for partial deterministic FSMs is PSPACE-complete [2]**
- **The length of a distinguishing sequence for a complete non-deterministic FSM with *n* states is in the worst case $O(2^n)$ [3]**
- **…**

How to decrease the complexity?

Utilizing scalable representations allows to 'hide' the complexity

- **Logic circuits**
- **Test Cases as FSMs**

Considering specific types of bugs in the software, i.e., specific fault models

- **White Box Testing**
- **User Defined Faults**

Providing **effective heuristics**

Specific truncating rules for the successor tree + effective traversal

Switching **from preset to adaptive** test derivation strategy

- **DS for non-deterministic FSMs**
- **HS for non-deterministic FSMs**

All of them are good for well-defined types of specifications

One of the test generation approaches with the reduced complexity

We propose how to derive tests with the guaranteed fault coverage w.r.t. the fault model <$\mathcal{S}$, ≈, *FD*> [4]

$\mathcal{S}$ can be **partial and non-deterministic** (non-observable even) but initialized

$$\Downarrow$$

- How to distinguish between $\mathcal{S}$ and a mutant $M \in FD$?

  FD is explicitly enumerated → complexity reduction trick

- A DS for the direct sum $\mathcal{S} \oplus M$ can be derived
- $\mathcal{S} \oplus M$ contains all the transitions that are included into FSM $\mathcal{S}$ and FSM M

DS derivation for a partial non-deterministic FSM

$S' = \{s_1, s_2\}$

- Derive a truncated successor tree (TST)

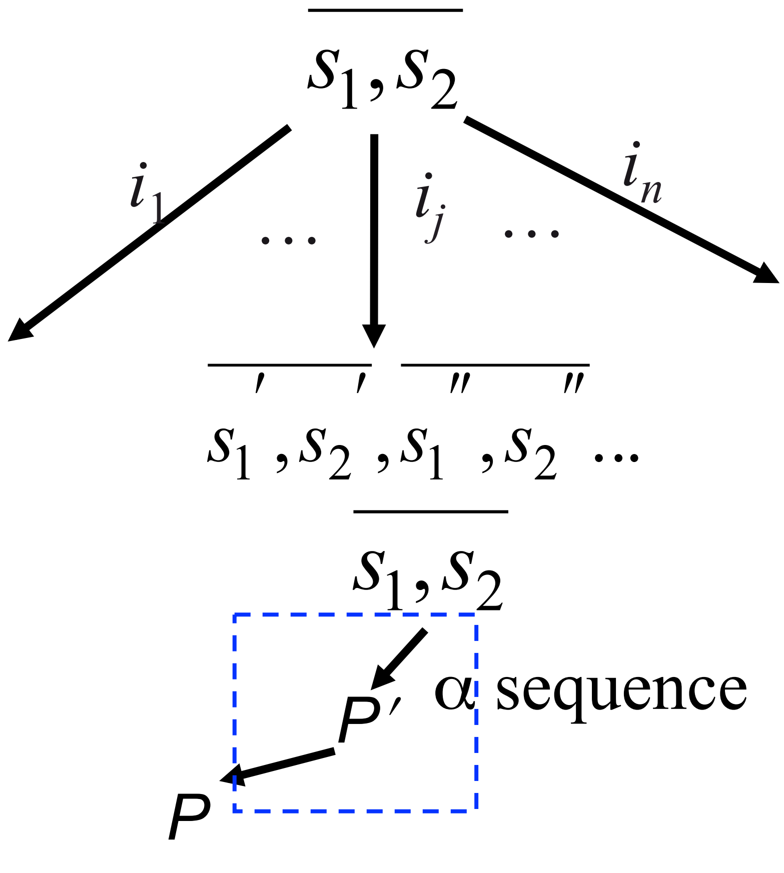
$\exists\, o_1\ ((s_1, i_j, o_1, s_1',) \in h_S\ \&\ (s_2, i_j, o_1, s_2') \in h_S\ \&\ s_1' \neq s_2')$

- Truncating rules

Rule 1 *P* is the empty set

Rule 2 Set *P* contains a subset that labels another node of the path from the root to the node labeled by the set *P*

Rule 3 *P* contains singleton



α is a distinguishing sequence iff it labels the path truncated by Rule 1

Deriving a test suite *TS* w.r.t. <$\mathcal{S}$, ≈, *FD*>

Input: FSM $\mathcal{S}$ which is initialized

Output: A test *TS* for $\mathcal{S}$ or a corresponding message

Step 1 $i = 0$

Step 2

Derive a current mutant M_i for the FSM $\mathcal{S}$

Derive a distinguishing sequence α for the pair of initial states of FSM $\mathcal{M}_i \oplus \mathcal{S}$

If there is no distinguishing sequence for the pair of initial states of the FSM $\mathcal{M}_i \oplus \mathcal{S}$, then

Return a corresponding message

Otherwise,

If $\alpha \notin TS$ then add α into the test suite *TS*

i++, and go to **Step 2**

The test suite length can be polynomial

Partial non-observable specification $\mathcal{S}$

Deterministic/ observable FSM $\mathcal{S}^o$

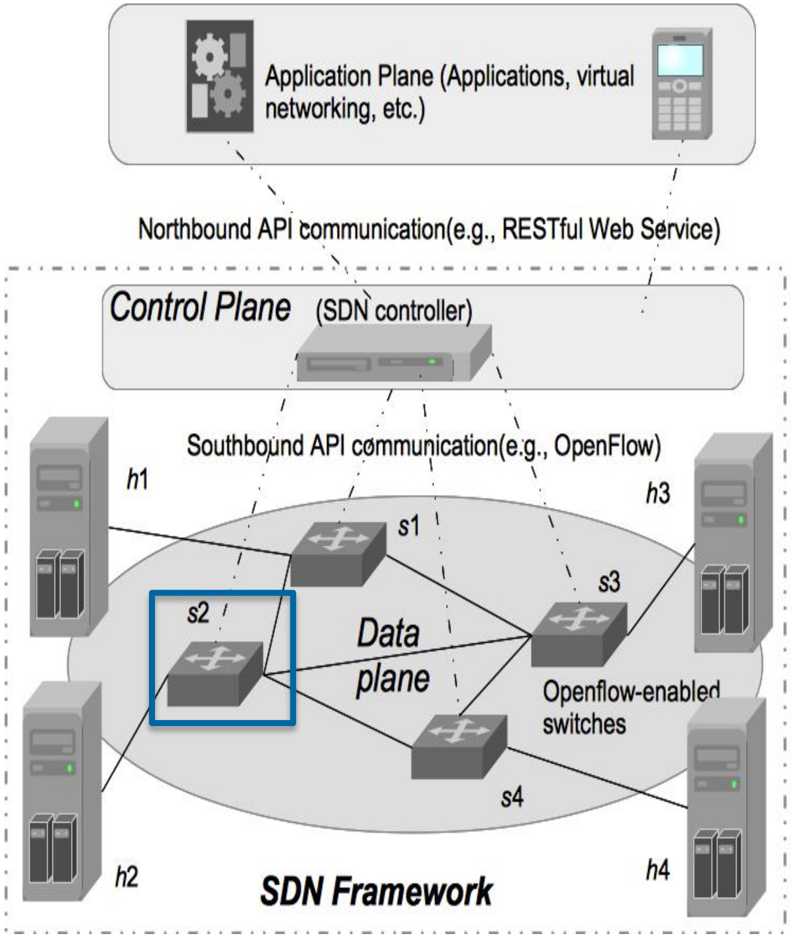
Maybe, the specification is 'good', i.e., allows an observable projection [5]?

Adaptive sequence (of a polynomial length) can be derived for the FSM $\mathcal{M}_i^o \oplus \mathcal{S}^o$

The number of mutants | *FD* | can also be polynomial

There can be an exhaustive test suite of a polynomial length w.r.t. <$\mathcal{S}$, ≈, *FD*> [4]

One of the possible applications



- An SDN-enabled switch is an SUT
- How to assure the reliable packet delivery???

- We consider a Fault Model *<S, =, FD>*
- The specification *S* is modeled via a logic circuit [6]
- User-Defined faults identify the mutants
- Distinguishing patterns for each mutant form the test suite

Our test suite detects the output and parameter faults in the action / matching part of the rules

Conclusions

- Theoretically: almost all the problems in (software) testing with guaranteed fault coverage have terrible complexity

- Practically: methods and tools for decreasing the complexity seem to be promising

⇓

New models need to appear and new methods and tools need to be provided to decrease the complexity

⇓

We do have something to tackle as a future work ☺

(Selected) references

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4. Hüsnü Yenigün, Natalia Kushik, Jorge López, Nina Yevtushenko, Ana R. Cavalli: Decreasing the complexity of deriving test suites against nondeterministic finite state machines. EWDTS 2017: 1-4
5. Natalia Kushik, Hüsnü Yenigün: Heuristics for Deriving Adaptive Homing and Distinguishing Sequences for Nondeterministic Finite State Machines. ICTSS 2015: 243-248
6. Asma Berriri, Jorge López, Natalia Kushik, Nina Yevtushenko, Djamal Zeghlache: Towards Model based Testing for Software Defined Networks. ENASE 2018: 440-446
7. …

THANK YOU!