Evolution of testing techniques: From active testing to monitoring techniques

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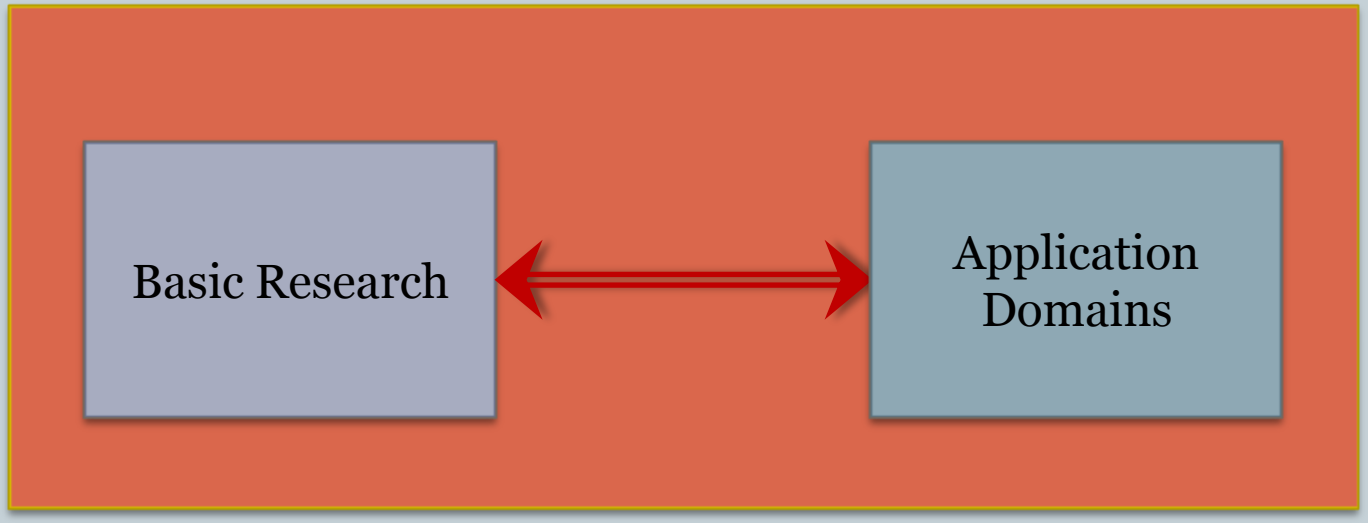
Motivation

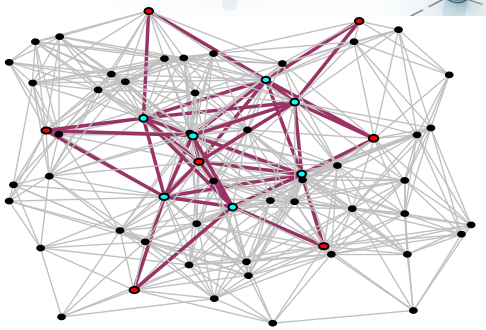
- Show the evolution of active testing to monitoring (passive testing) techniques
- Explain the differences and complementarity of these techniques
- Present some representative examples

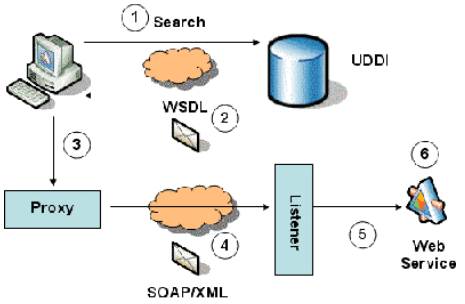
A collaborative model of research

- Our research model is based in:
  - Basic and applied research
  - Evaluation of results in real environments
  - Strong collaboration with industrial partners



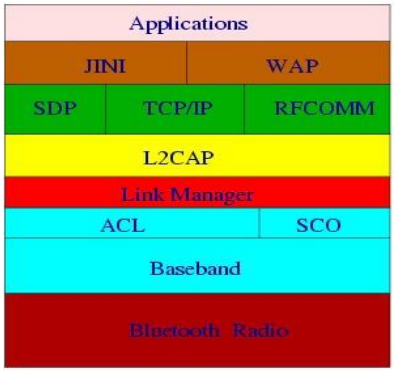
Different Application Domains





DETAILED WEB SERVICES PROCESS

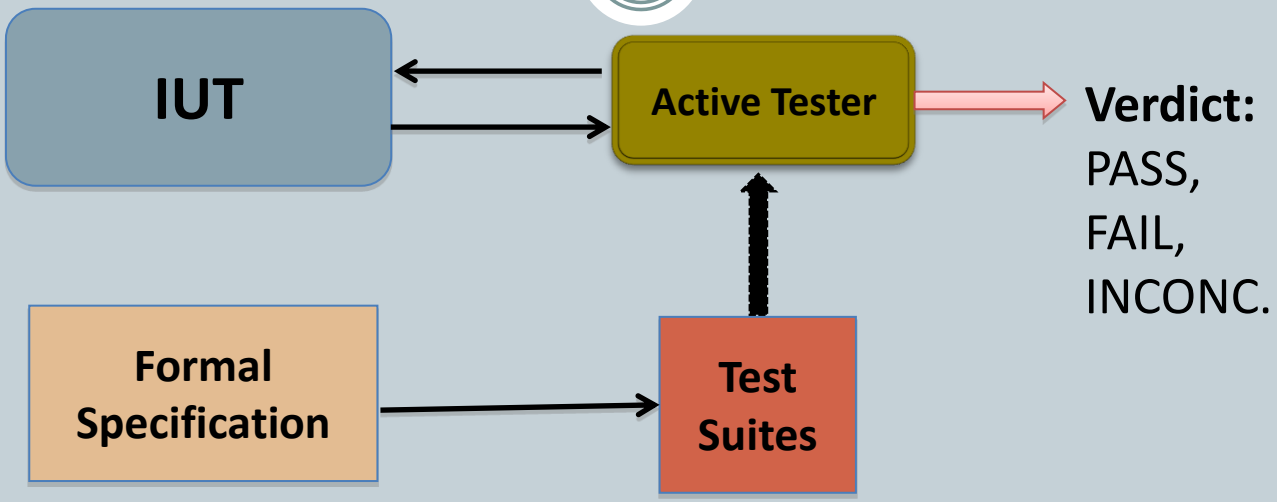
Figure 1: The process flow of a Web service



Testing

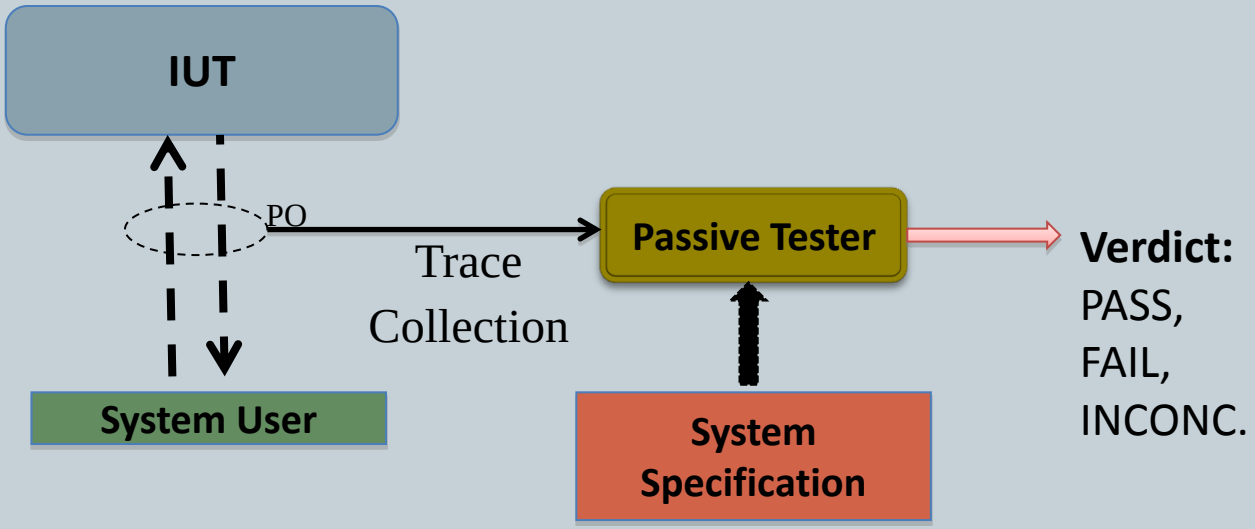
- Testing: The process of executing software with the intent of finding and correcting faults
- Conformance testing: The process of checking if the implementation under test conforms the specification
  - Two techniques: active and passive testing (monitoring)
  - This presentation will focus mostly on monitoring, but there are many common objectives and challenges with active testing

What is active testing ?



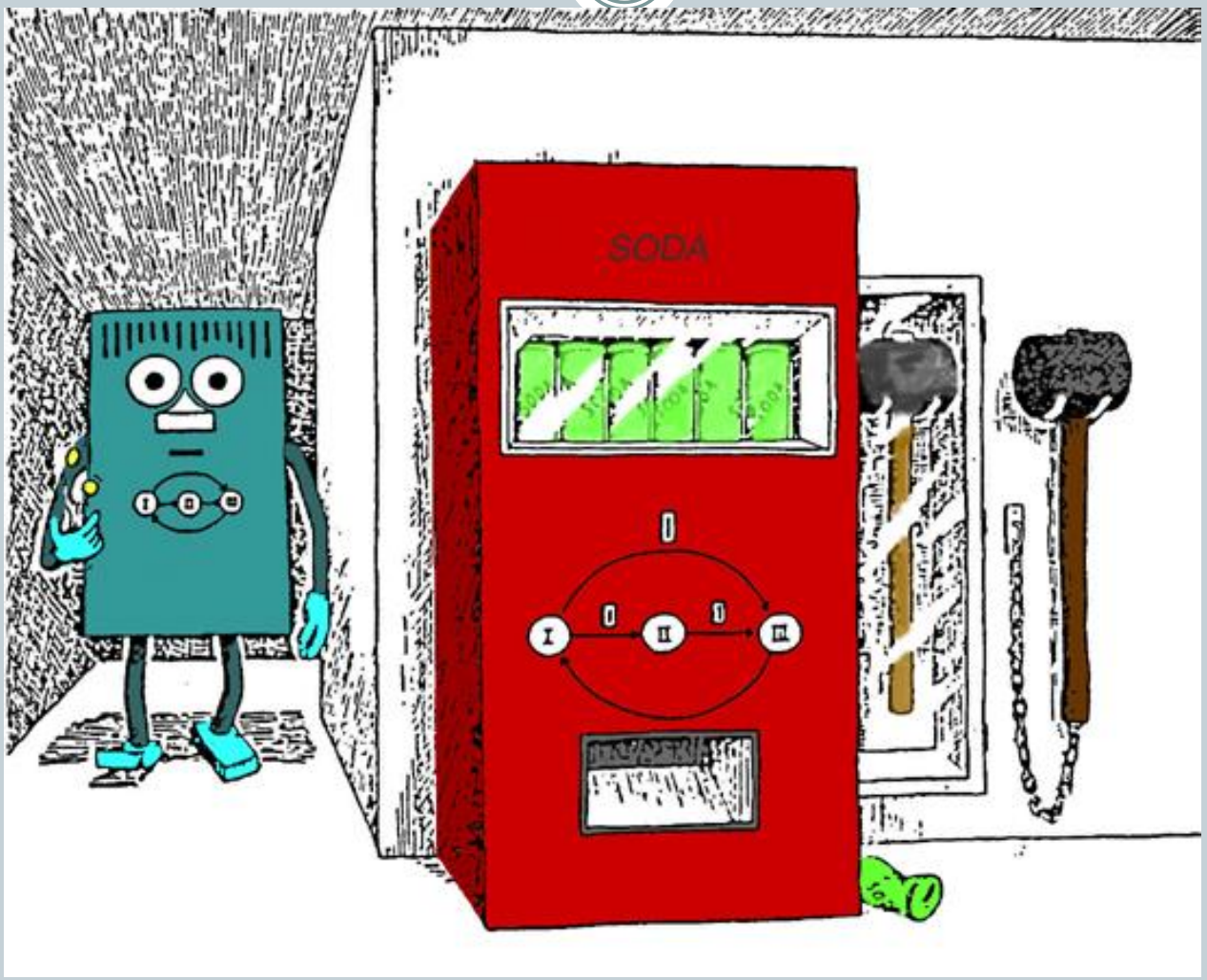
- Usually called Model Based Testing (MBT)
- It is assumed that the tester controls the implementation. Control means: after sending an input and after receiving an output, the tester knows what is the next input to be send
- The tester can guide the implementation towards specific states
- Automatic test generation methods can be defined
- Usually a test case is a set of input sequences

What is monitoring (passive testing) ?



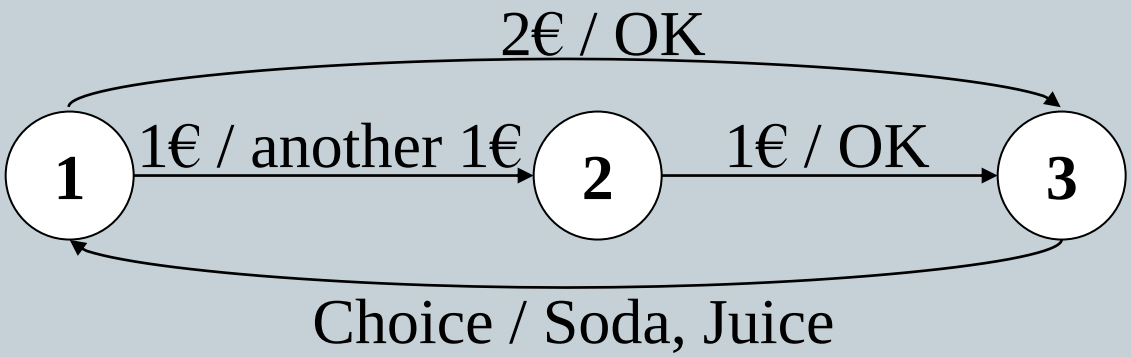
- Passive testing consists in analyzing the traces recorded from the IUT and trying to find a fault by comparing these traces with either the complete specification or by verifying some specifics requirements (or properties) during normal runtime
- No interferences with the IUT
- It is also referred to as monitoring

Fault models for active testing
Example: Soda vending machine

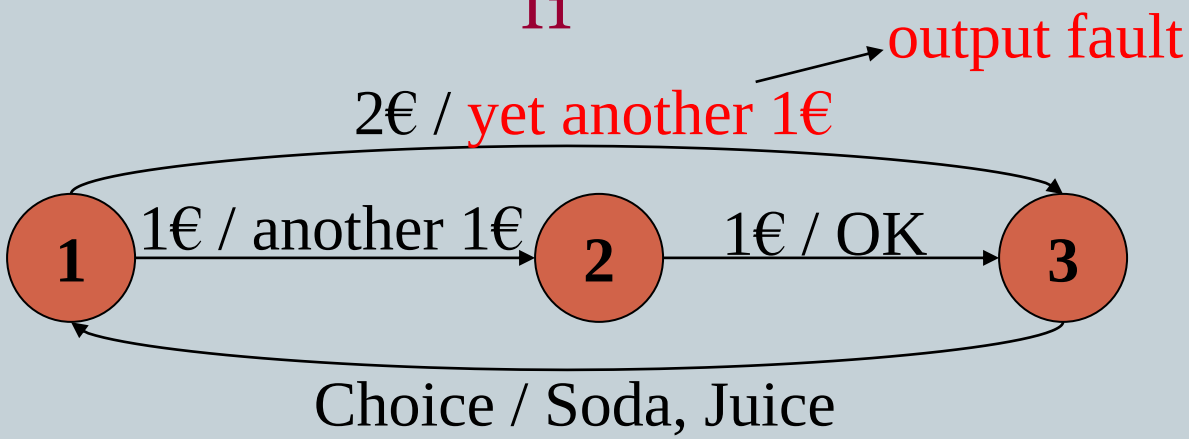


Example: Soda Vending Machine

Specification

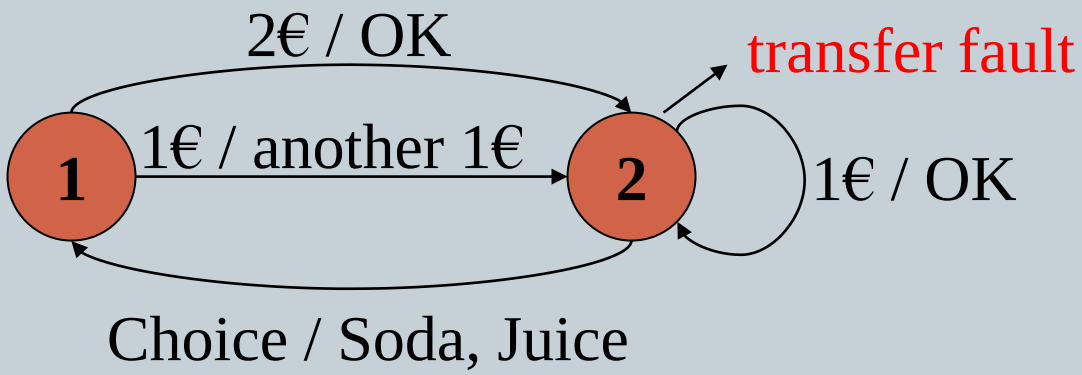


I1

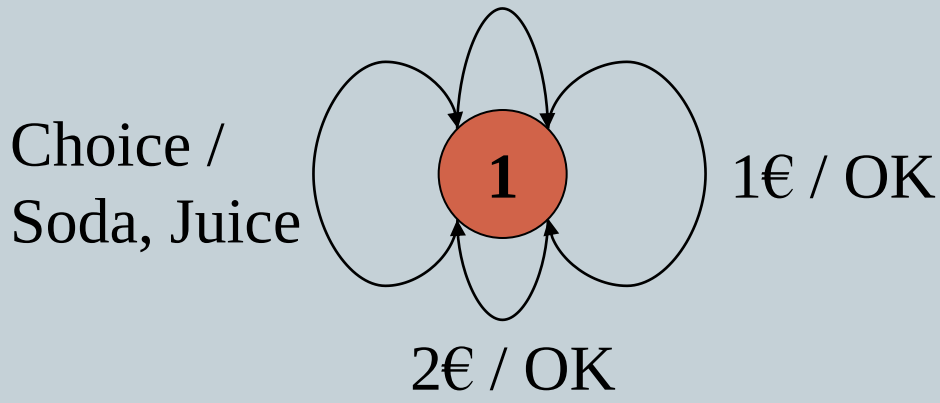


Example: Soda Vending Machine

I2



I3

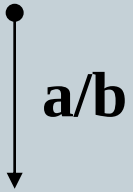


Controllability issue in active testing

- How to bring the finite state machine implementation into any given state at any given time during testing ?
  - Non trivial problem because of limited controllability of the finite state machine implementation
  - It may not be possible to put the finite state machine into the head state of the transition being tested without realizing several transitions

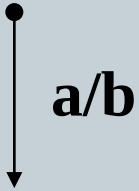
Controllability: examples

Specification



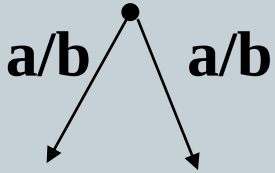
Controllable

Imp1



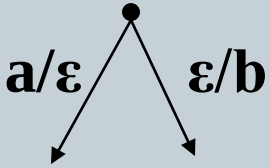
Non controllable

Imp2

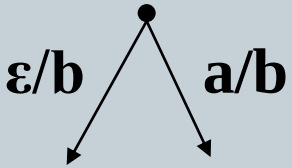


Non controllable

Imp3

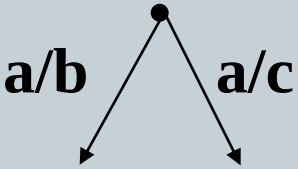


Imp4



Controllable under fairness assumption

Imp5



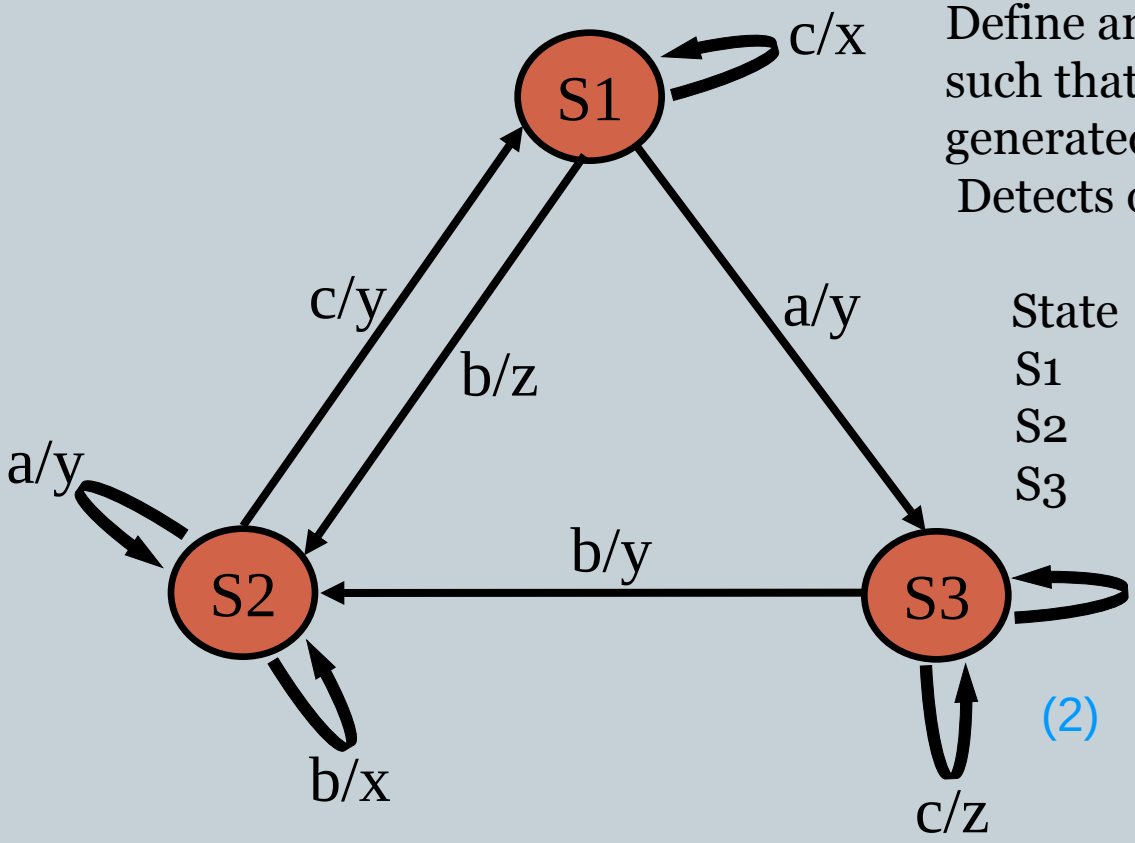
Observability issue in testing

- How to verify that the finite state machine implementation is in a correct state after input/output exchange?
  - *State identification* problem. Difficult because of limited observability of the finite state machine implementation, it may not be possible to directly verify that the finite state machine is in the desired tail state after the transition has been fired

Solutions to observability issue

- To solve this problem different methods have been proposed:
  - DS (Distinguishing Sequence)
  - UIO (Unique Input/Output Sequence)
  - W (Distinction Set)

Unique Input/Output sequence (UIO sequence)



Define an input sequence for each state such that the output sequence generated is unique to that state.
Detects output and transfer faults.

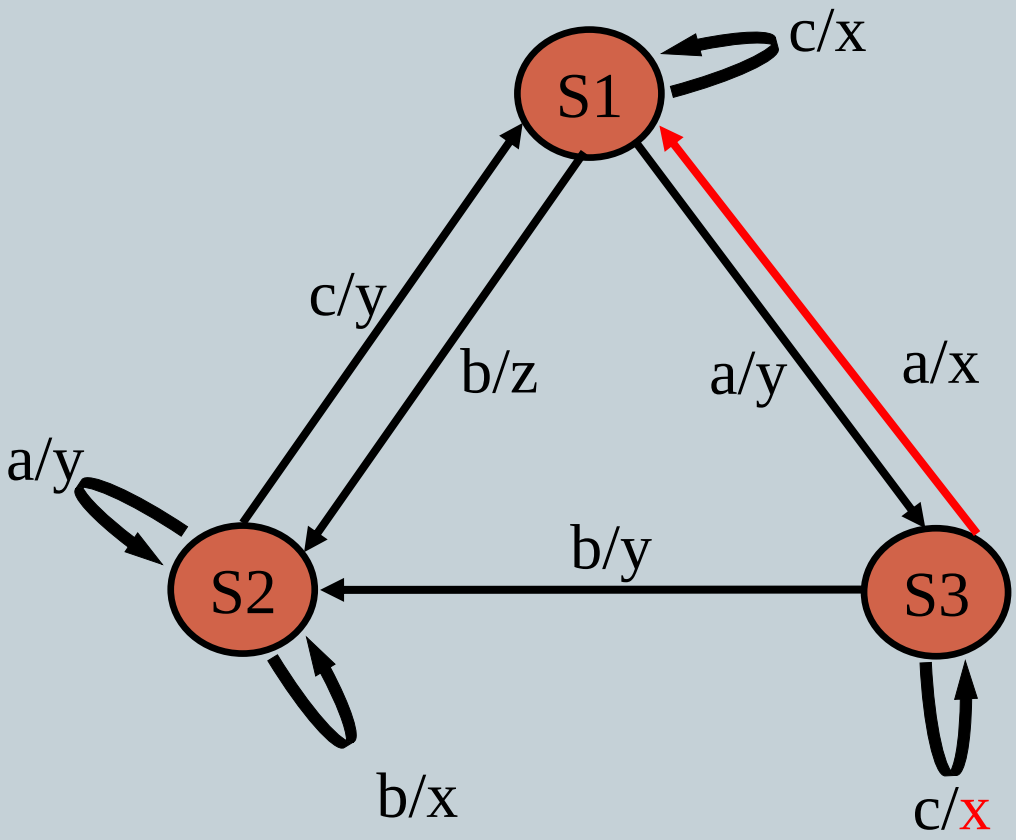
State	UIO sequences
S1	c/x
S2	c/y
S3	b/y

(1)

(2)

Test of (1): a/y a/x b/y
Test of (2): a/y c/z b/y

Transfer and output error detection



Faulty Implementation

Test of (1): a/y a/x b/y
Test of (2): a/y c/z b/y

Application du test of (1) to the implementation: a/y a/x b/z (transfer error)

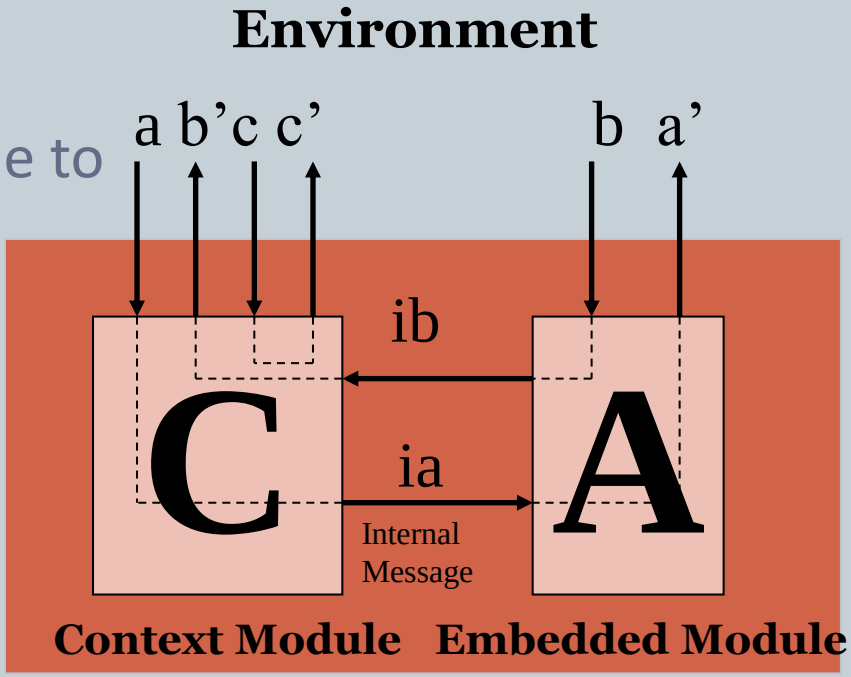
Application of test (2) to the implementation: a/y c/x (output error)

Limitations of active testing

- Non applicable when no direct access to the implementation under test
- Semi- controllable interfaces (component testing)
- Interferences on the behaviour of the implementation

Components Testing

- Test in context, embedded testing:
  - Tests focused on some components of the system, to avoid redundant tests
  - Interfaces semi-controllables
  - In some cases it is not possible to apply active testing



Why passive testing?

- **Conformance testing is essentially focused on verifying the conformity of a given implementation to its specification**
  - It is based on the ability of a tester that stimulates the implementation under test and checks the correction of the answers provided by the implementation
- **Closely related to the controllability of the IUT**
  - In some cases this activity becomes difficult, in particular:
    - if the tester has not a direct interface with the implementation
    - or when the implementation is built from components that have to run in their environment and cannot be shutdown or interrupted (for long time) in order to test them

Controllability and observability issues in passive testing

- **Controllability**
  - No **controllability** issue because no interaction with the implementation under test
- **Observability**
  - It is assumed that to perform passive testing it is necessary to observe the messages exchanges between modules.
  - Passive testing is a Grey Box testing technique
- **Fault detection using passive testing**
  - It is possible to detect output faults
  - It is possible to detect transfer faults under some hypothesis: to initialise the IUT in order to be sure that the implementation is in the initial state and then perform passive testing

Invariant based passive testing approach

- In this approach a set of properties are extracted from the specification or proposed by the protocol experts, and then the trace resulting from the implementation is analyzed to determine whether it validates this set of properties.

- These extracted set of properties are called invariants because they have to hold true at every moment.

Invariant based passive testing approach

- Definition: an invariant is a property that is always true.
- Two test steps:
  - Extraction of invariants from the specification or proposed by protocol experts
  - Application of invariants on execution event traces from implementation
- Solution: I/O invariants

Test by invariants: I/O invariants

- An invariant is composed of two parts :
  - The test (an input or an output)
  - The preamble (I/O sequence)
- 3 kind of invariants :
  - Output invariant (simple invariant)
  - Input invariant (obligation invariant)
  - Succession invariant (loop invariant)

Test by invariants : Simple (Output) invariant

- Definition : invariant in which the test is an output
- Meaning : « immediatly after the sequence *préambule* there is always the expected output »
- Example :

$(i_1 / o_1) (i_2 / o_2)$

(preambule in blue, expected output in red)

Test by invariants : Obligation (Input) invariant

- Definition : invariant in which the test is an input
- Meaning : « immediatly before the sequence *preamble* there is always the input *test* »
- Example :

$(i_1 / o_1) (i_2 / o_2)$

(preamble in blue, test in red)

Test by invariants : succession invariant

- Definition : I/O invariant for complex properties (loops …)
- Example :
  - the 3 invariants below build the property : « only the third i_2 is followed by o_3 »

$(i_1 / o_1)\ (i_2 / o_2)$

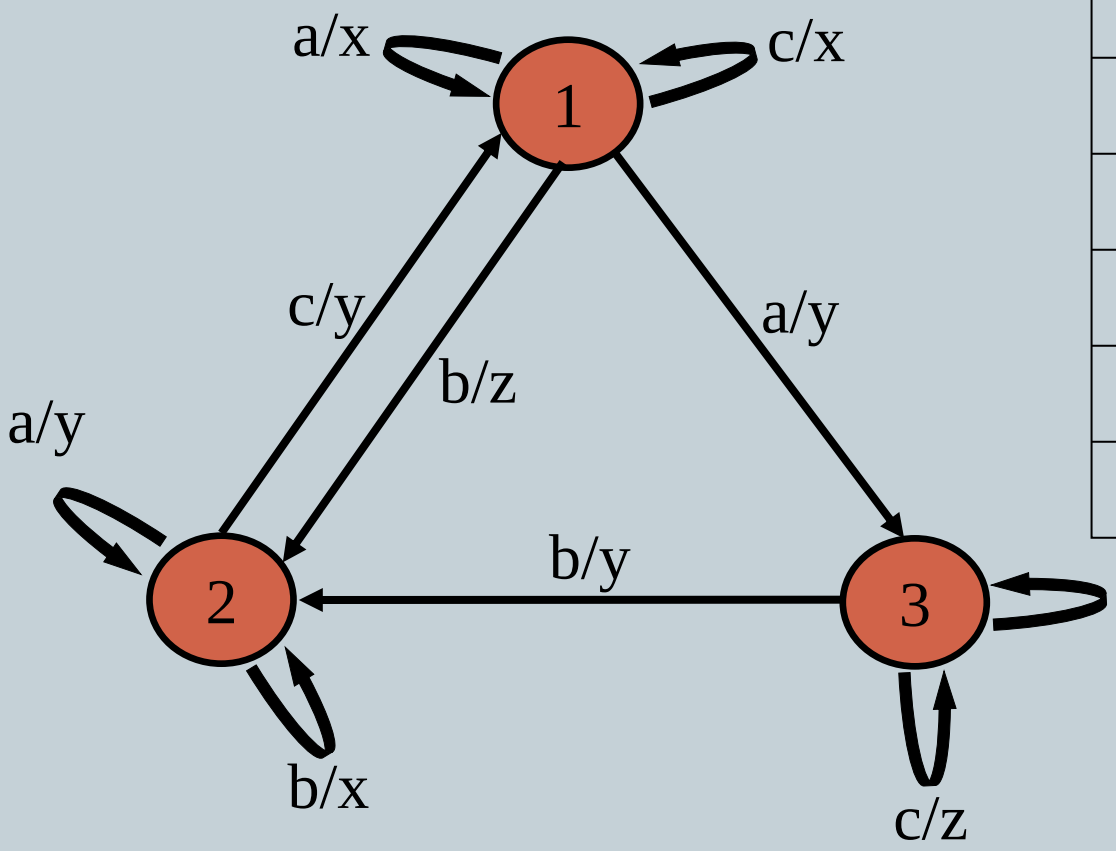
$(i_1 / o_1)\ (i_2 / o_2)\ (i_2 / o_2)$

$(i_1 / o_1)\ (i_2 / o_2)\ (i_2 / o_2)\ (i_2 / o_3)$

Simple invariant

- A trace as $i_1/o_1,\ldots, i_{n-1}/o_{n-1}, i_n/\boldsymbol{O}$ is a simple invariant if each time that the trace $i_1/o_1,\ldots, i_{n-1}/o_{n-1}$ is observed, if we obtain the input i_n then we necessarily get an output belonging to $\boldsymbol{O}$, where $\boldsymbol{O}$ is included in the set of expected outputs.
- $i/o, *, i'/\boldsymbol{O}$ means that if we detect the transition i/o then the first occurrence of the symbol i' is followed by an output belonging to the set $\boldsymbol{O}$.
- * replaces any sequence of symbols not containing the input symbol i' and *?* replaces any input or output.

Example

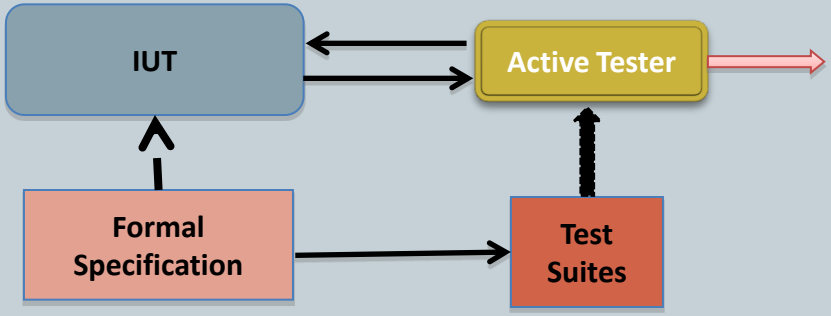


Invariants	Verdict
a/?, c/z, b/{y}	*True*
b/z, a/{x}	*False*
a/x, *, b/{y, z}	*True*
a/y, ?/$\overline{\{z\}}$	*False*
a/$\overline{\{x\}}$	*False*
a/x, *, ?/$\overline{\{y\}}$	*True*

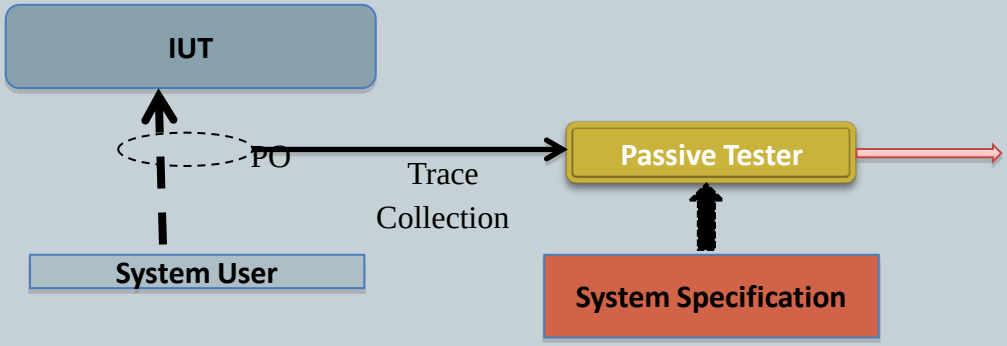
Traces

a/y c/z b/y a/y a/x c/z b/y
c/x a/y a/x c/z b/y
c/y a/x b/z b/x a/y

Passive vs Active Testing



- ☺ Possibility to focus on a specific part of the specification
- ☺ Full test generation automation
- ☹ Needs a model
- ☹ May modify (crash) the IUT behavior



- ☺ No interferences with the IUT
- ☺ No models needed
- ☺ Full monitoring automation
- ☹ Grey box testing

Run Time Verification

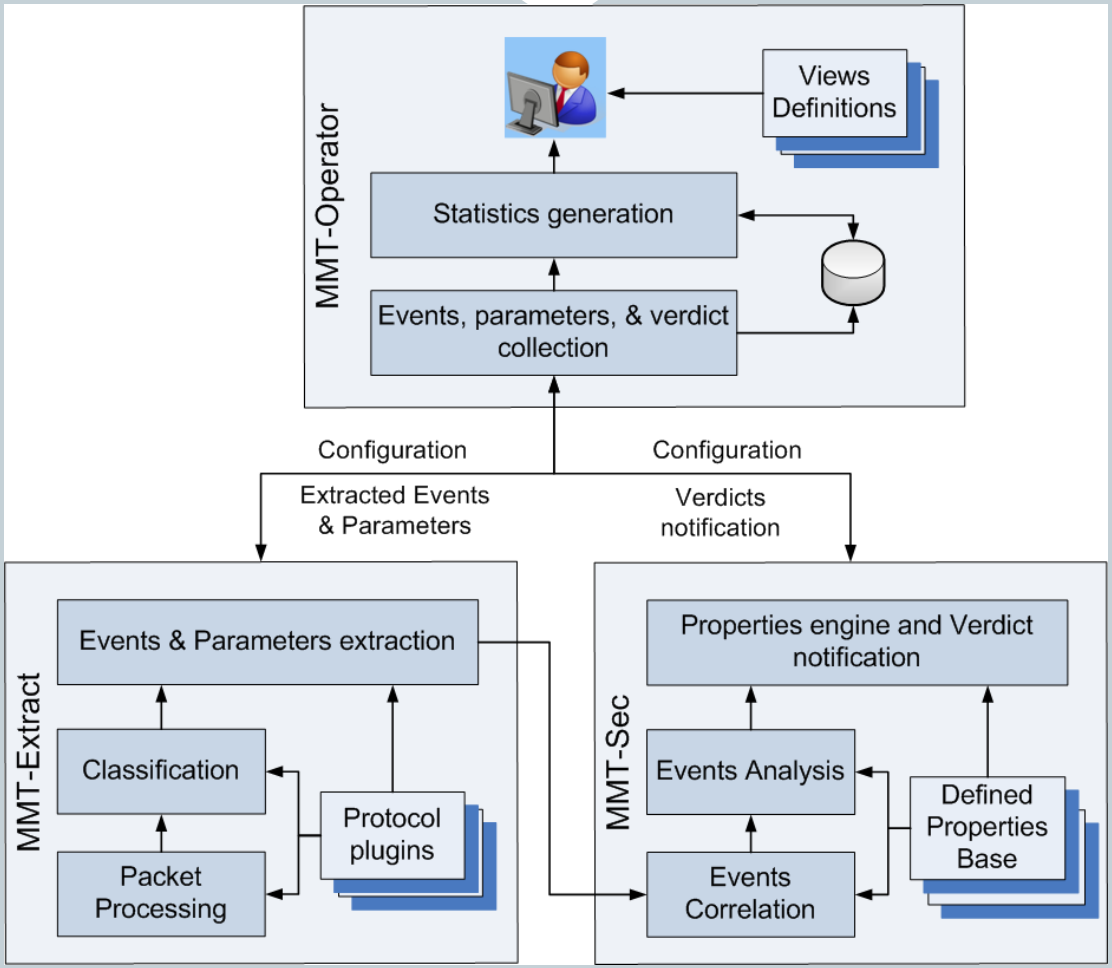
- Approach proposed by researchers of verification (model checking) community
- Passive testing developed by the testing community
- EAGLE and RuleR tools proposed by Barringer and al. in 2004 and 2010 respectively, based on temporal logics and rewriting rules for properties description
- Others tools: Tracematches, [Avgustinov et al. 2007], J-LO [Bodden 2005]and LSC [Maoz and Harel 2006]

Monitoring

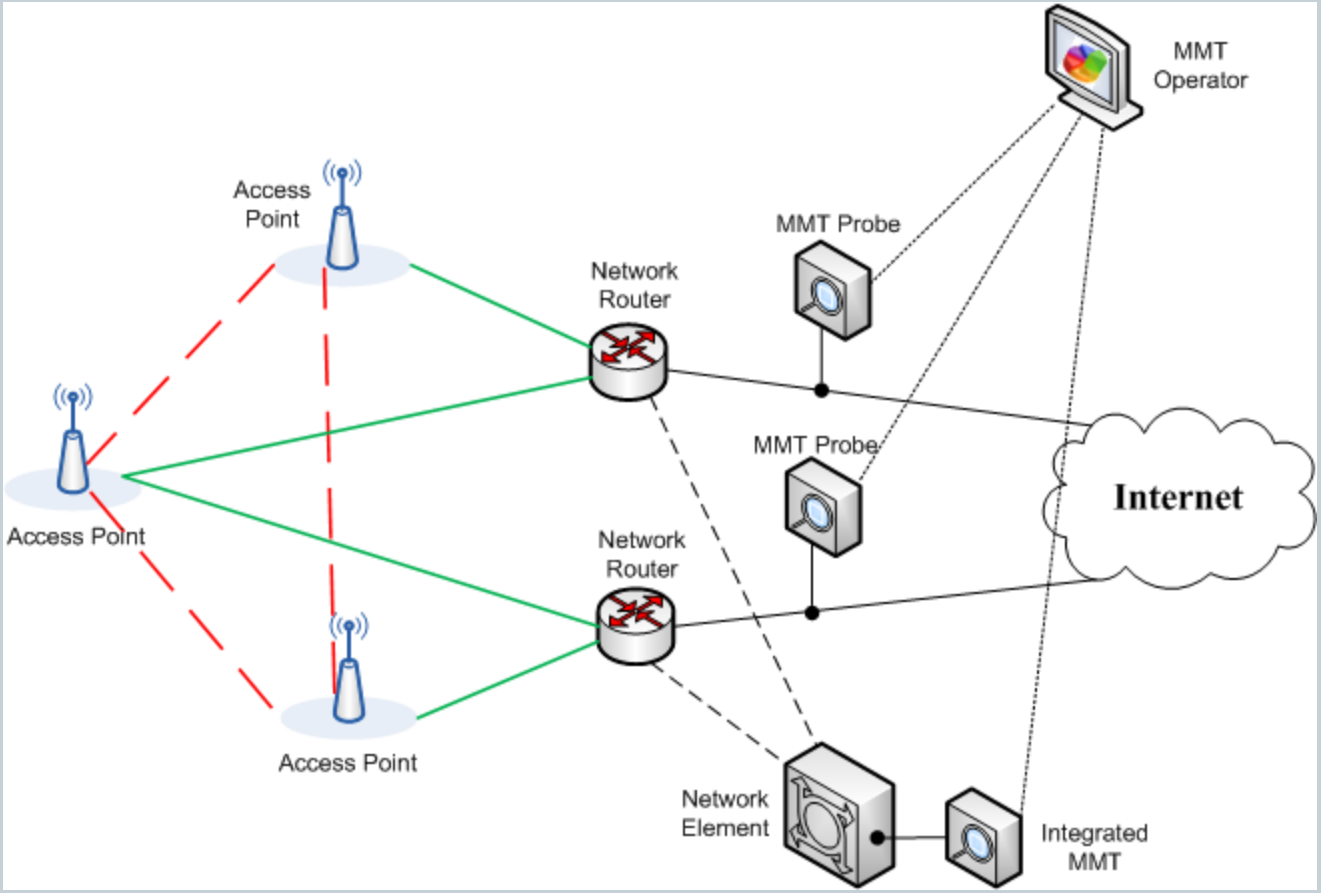
How we see monitoring

- Monitoring the traces of a running system (e.g., traffic or message flows), **online or offline**.
- **Non-obtrusive** (i.e., execution traces are observed without interfering with the behaviour of the system).
- Analyzing collected data according to functional and non-functional requirements:
  - **Security properties** described in a formal specification (temporal logic , regular expressions, describing behaviour involving several events over time).
  - **Performance** to get real time visibility over the traffic statistics, KPI, delivered QoS, etc.
- Extended to perform **counter-measures**.

Monitoring tool (MMT) description



MMT in a transport network scenario



TESTING & MONITORING AN ELECTRONIC VOTING SYSTEM

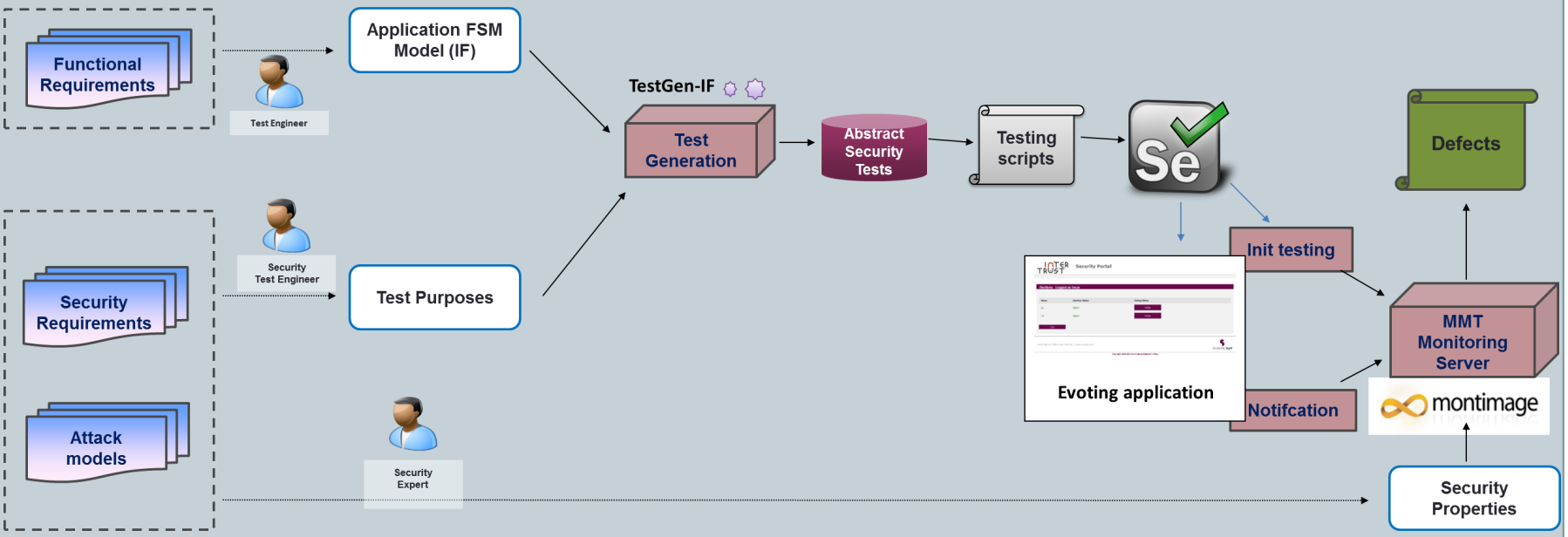
Context

- INTER-TRUST project. Three-year project with many academic and industrial partners
- Security properties of services
- Detection of attacks using active and monitoring techniques

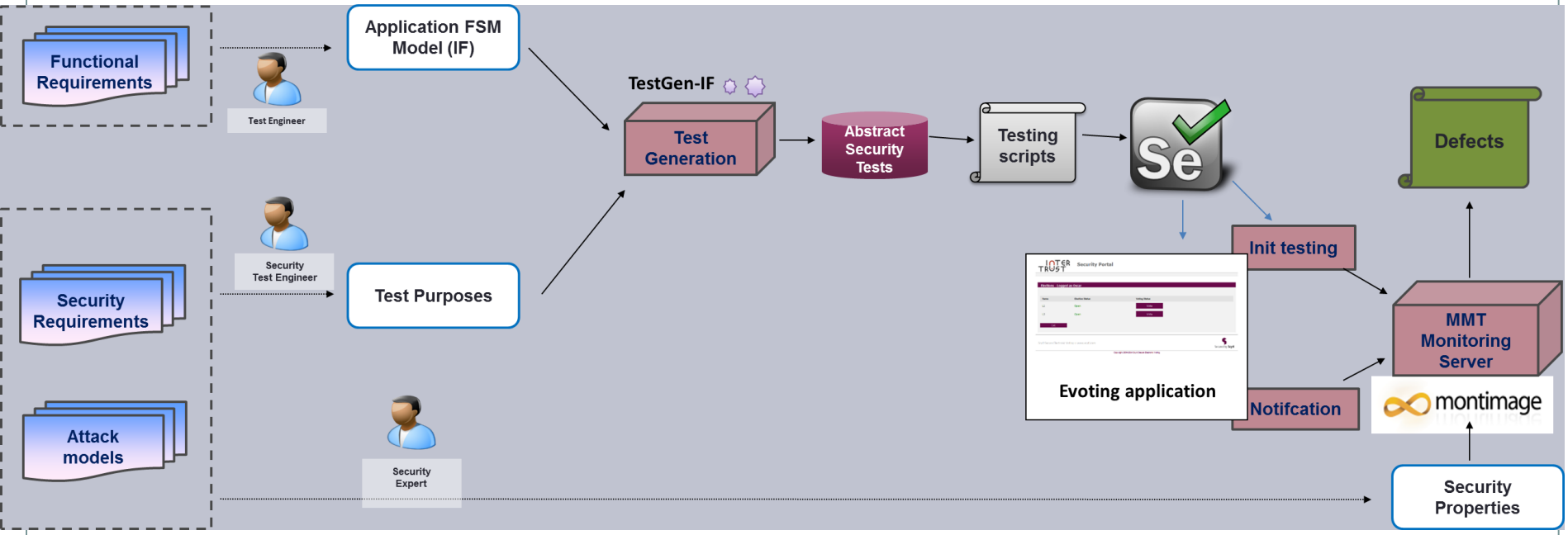
MOTIVATION

- Why testing ? (testing phase)
  - Vulnerabilities can be introduced by AOP (Aspect Oriented Programming) used in Inter-trust
    - Functional testing
    - Check the respect of weaved security policies (aspects)
    - Check the robustness of the target application
    - Detect vulnerabilities
    - Simulate attacks
- Why monitoring ? (testing & operation phases)
  - Same as above
  - + detecting context changes (context awareness) at runtime

Model based testing: TestGen-IF

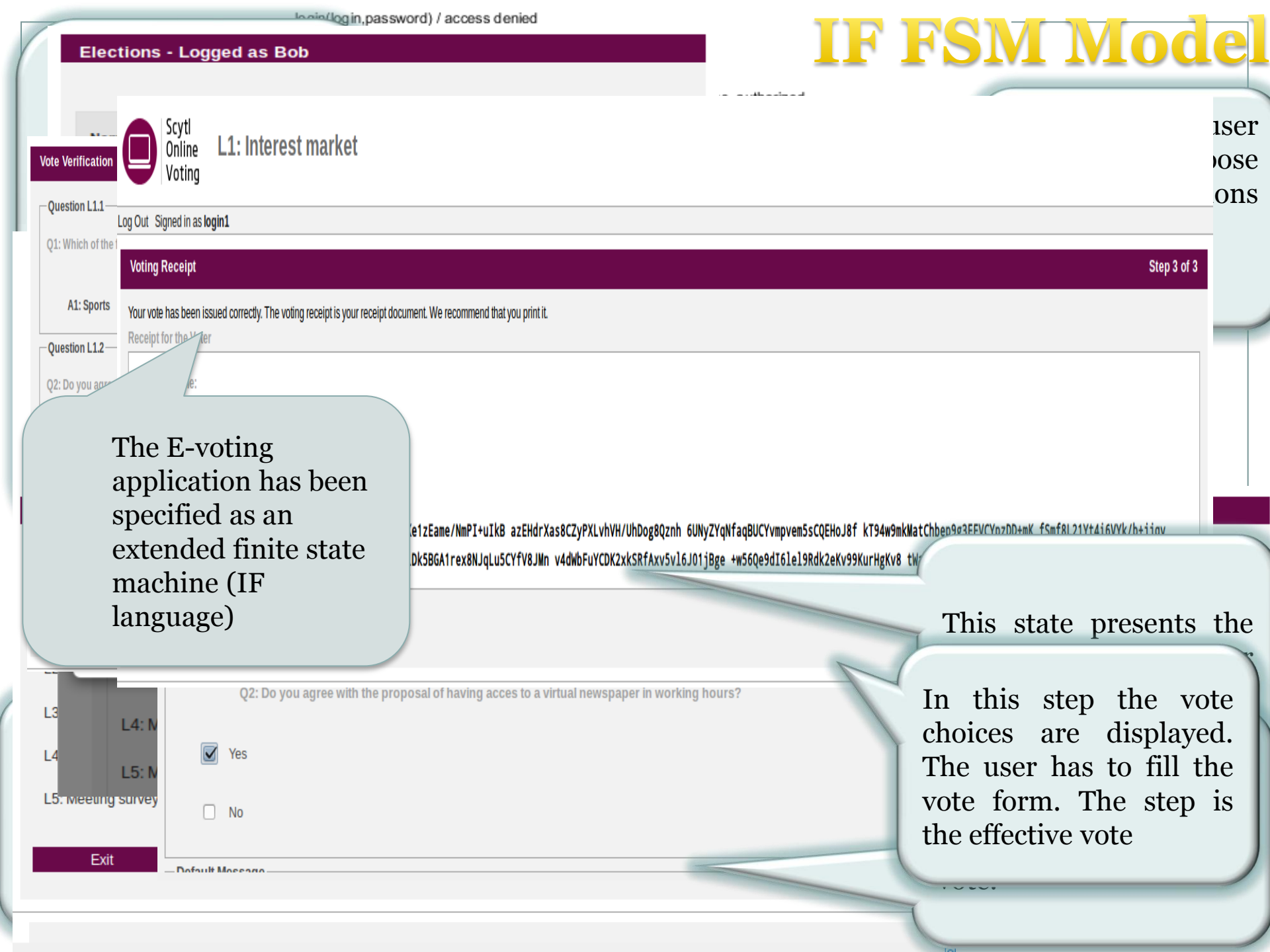


Model based testing: TestGen-IF

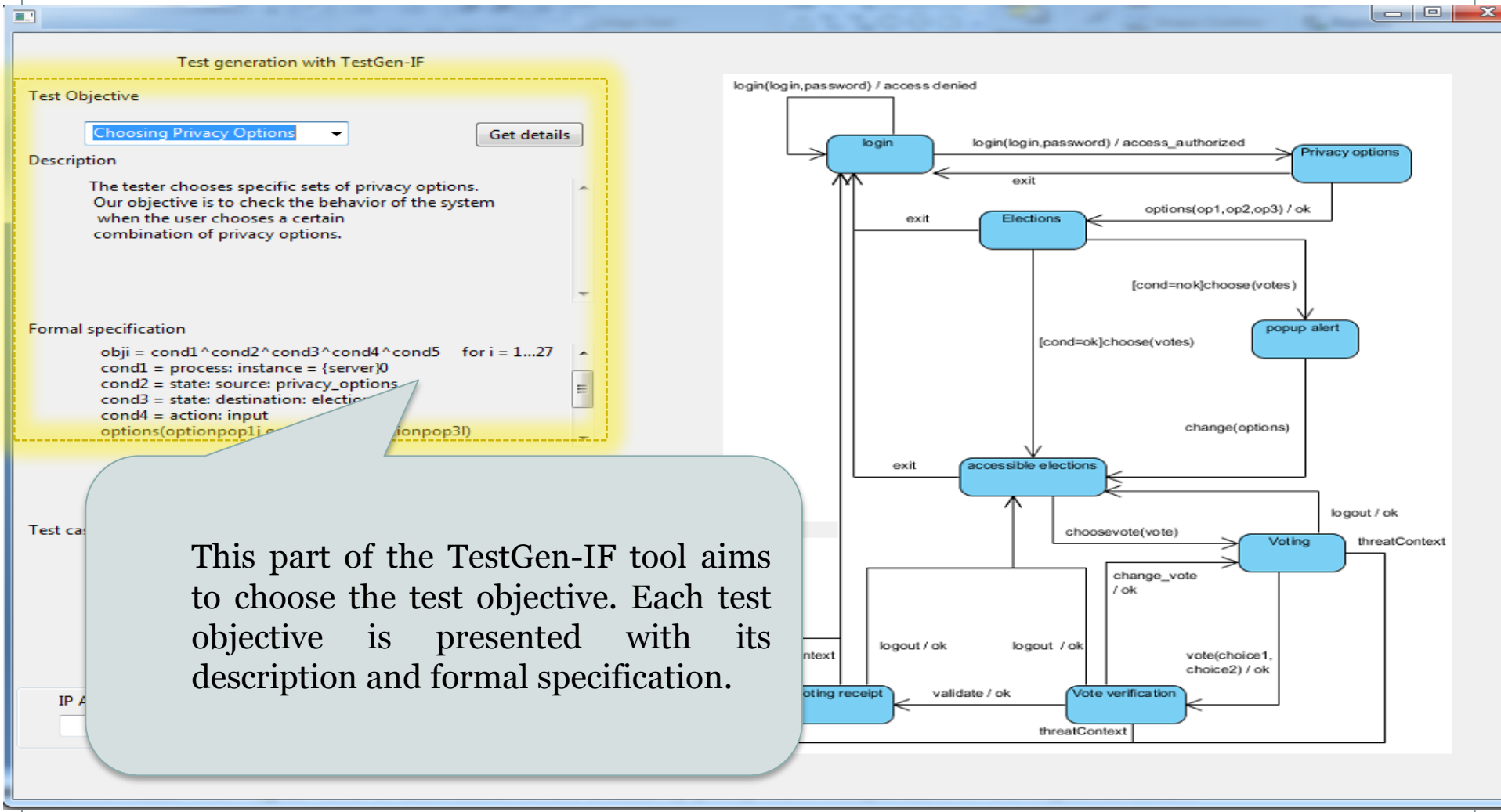


- Generation of tests from IF model and test purposes
  - Target: functional, security properties, attacks
- Execution relying on Selenium (Web interface)
- Detecting failures using MMT

IF FSM Model

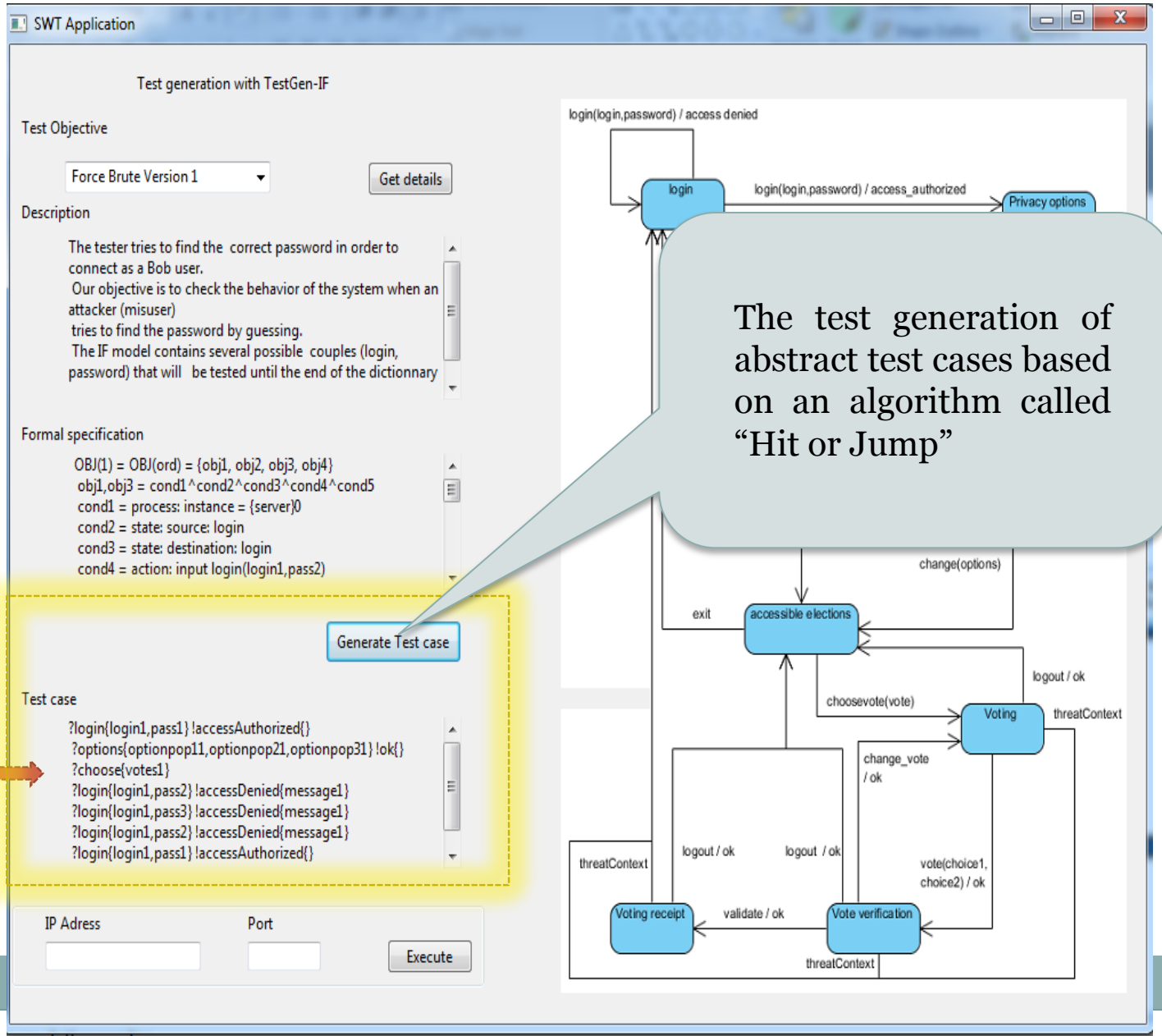

login(login,password) / access denied
Elections - Logged as Bob
Scytl Online Voting
L1: Interest market
Vote Verification
Question L1.1
Log Out Signed in as login1
Voting Receipt
Step 3 of 3
Your vote has been issued correctly. The voting receipt is your receipt document. We recommend that you print it.
Question L1.2
A1: Sports
Q2: Do you agree with the proposal of having acces to a virtual newspaper in working hours?
Yes
No
Exit
The E-voting application has been specified as an extended finite state machine (IF language)
This state presents the
In this step the vote choices are displayed. The user has to fill the vote form. The step is the effective vote

Test Objectives Specification



This part of the TestGen-IF tool aims to choose the test objective. Each test objective is presented with its description and formal specification.

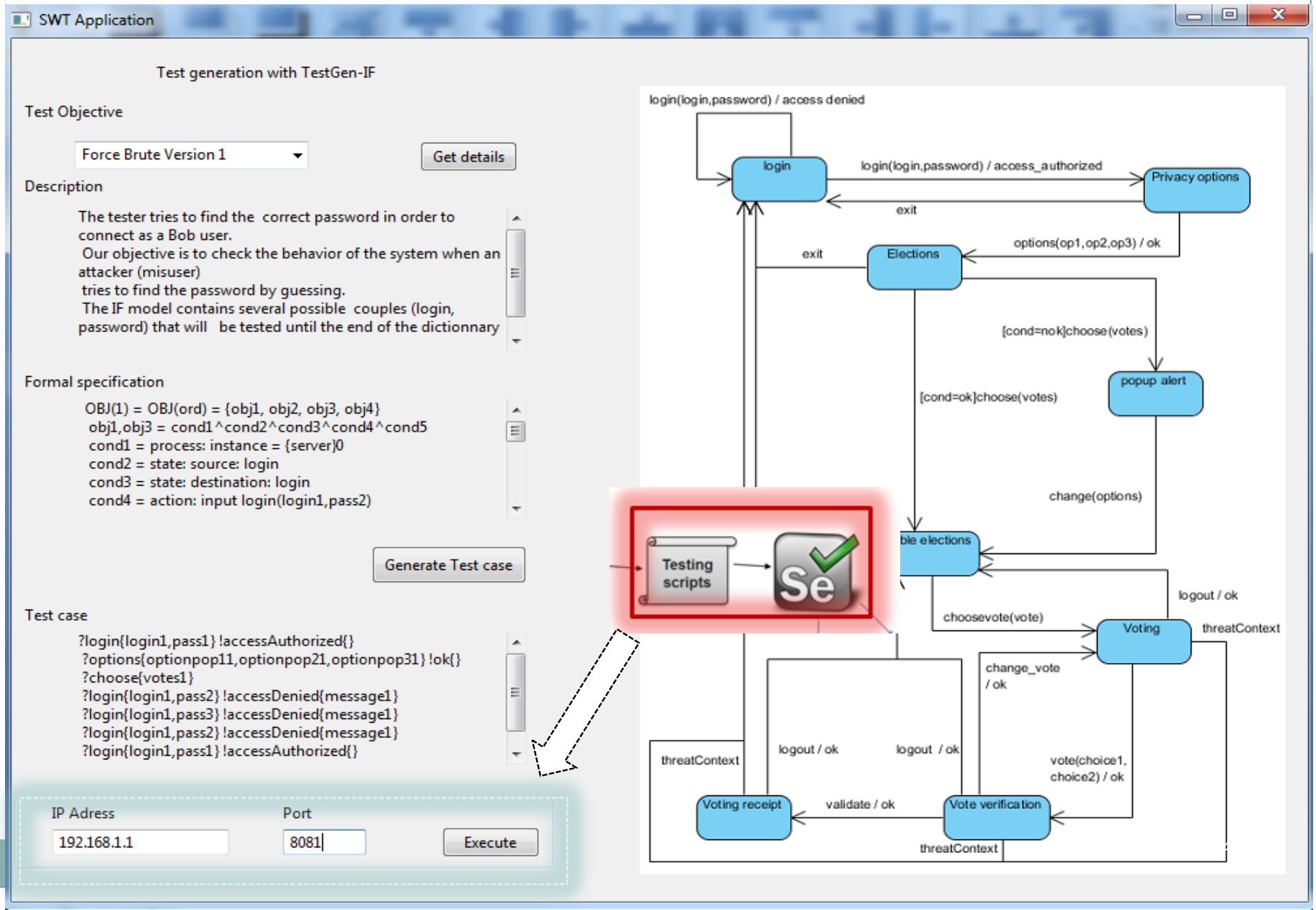
Test Case Generation



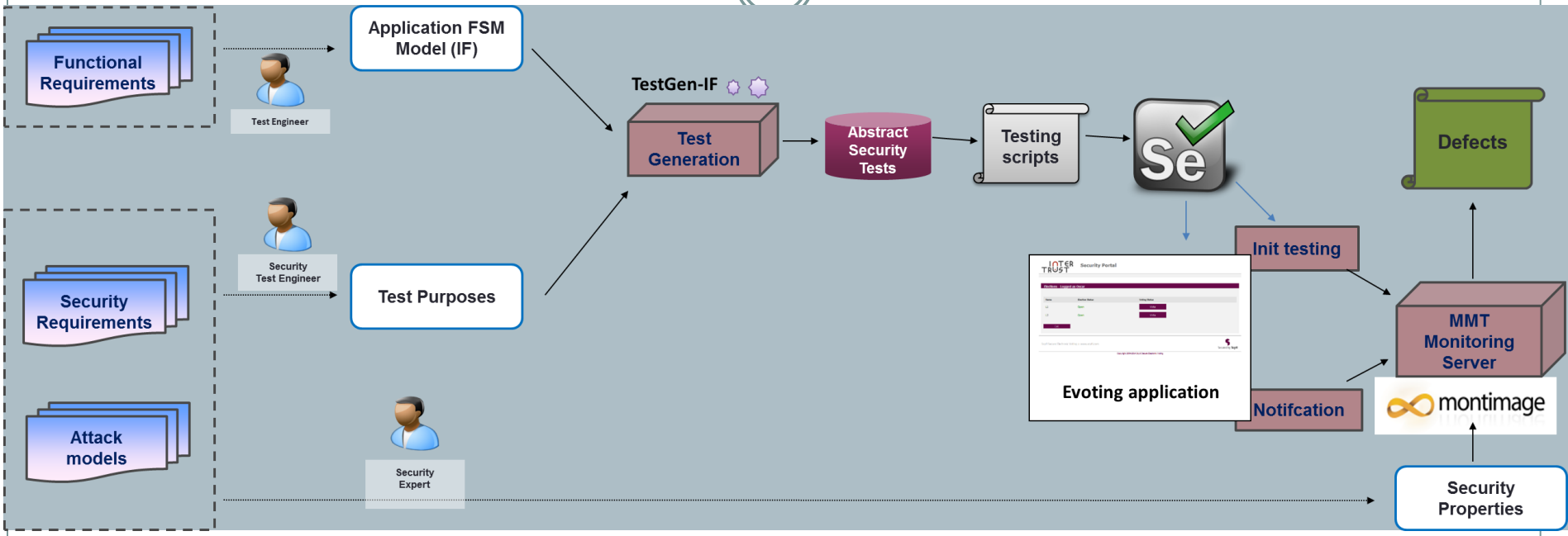
The test generation of abstract test cases based on an algorithm called "Hit or Jump"

Abstract Security Tests

Automatic Test Execution



Monitoring Tool (MMT)

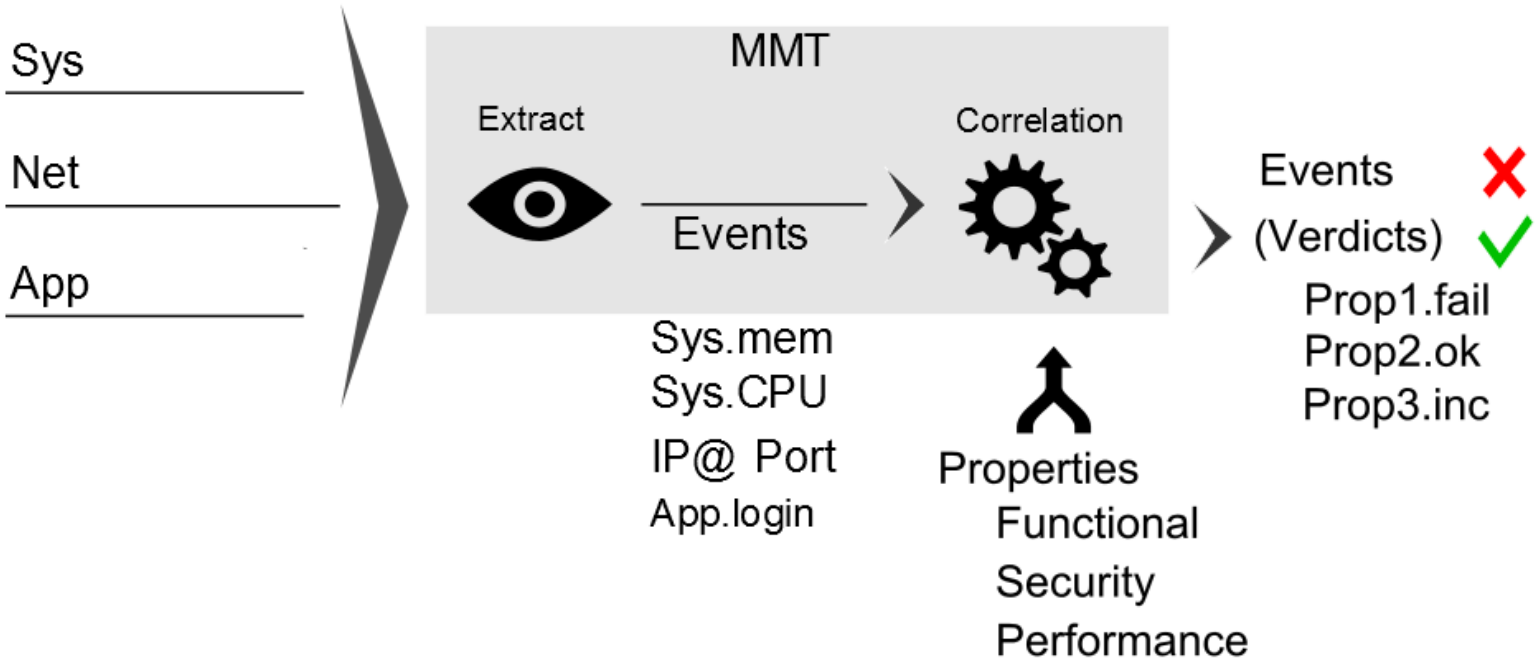


- Detecting failures using MMT
  - Events based detection
  - Properties as FSMs or as LTL properties

Monitoring

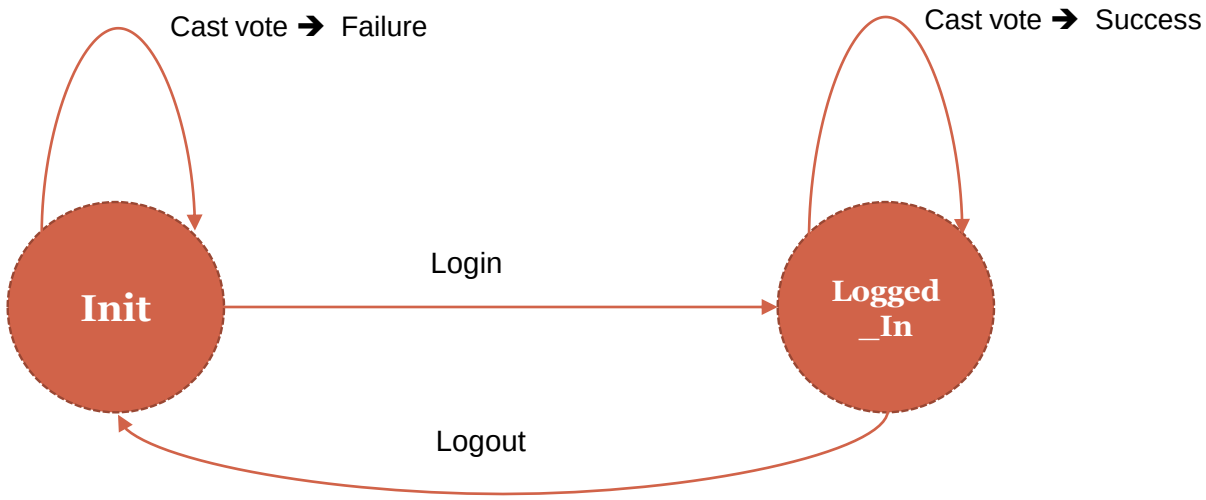
- Two main uses:
  - During the testing phase to complement the testing tools and provide a verdict
  - During the operation phase to monitor security and application context
- Relies on data collected at different levels
  - Network (ex. CAM messages)
  - Application internal events (notification module)
  - System status (CPU and memory usage)

Montimage Monitoring Tool

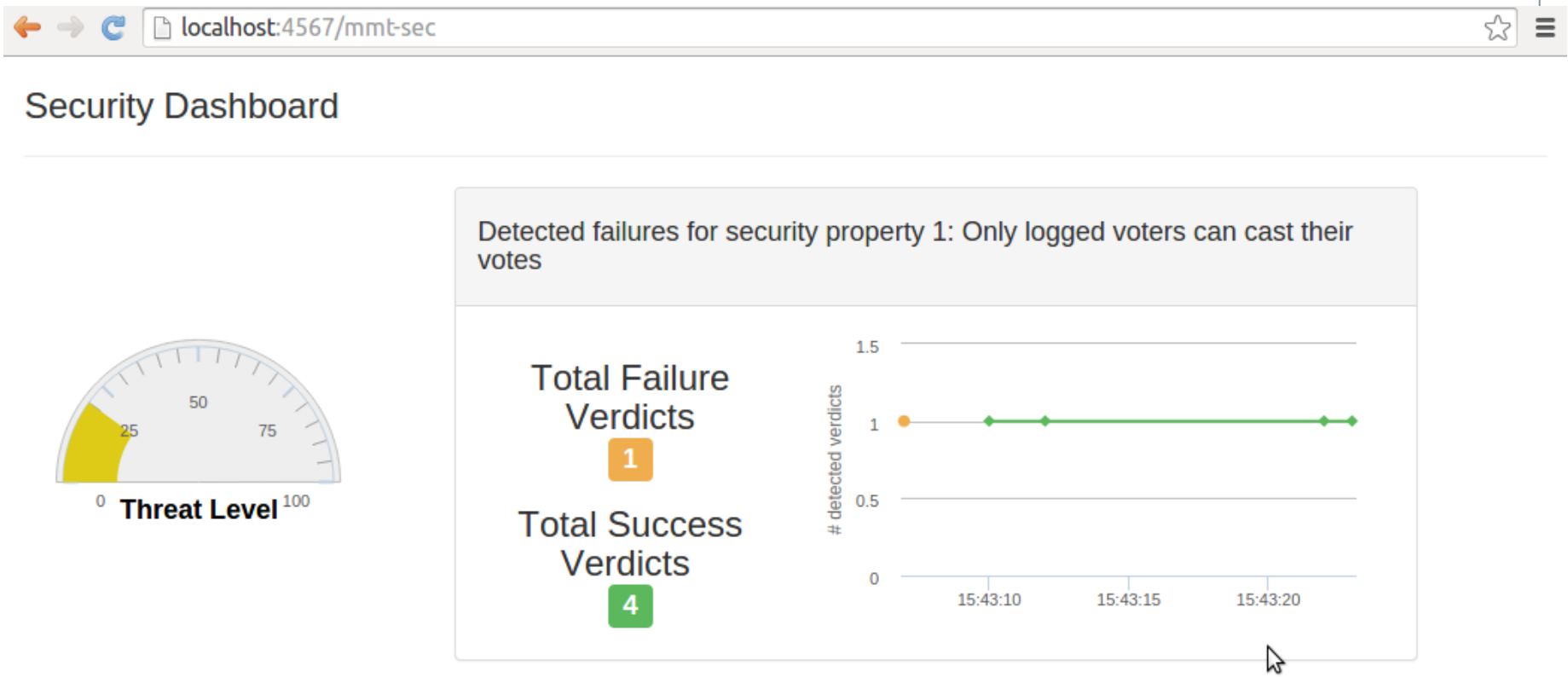


Analysis and Failure Detection

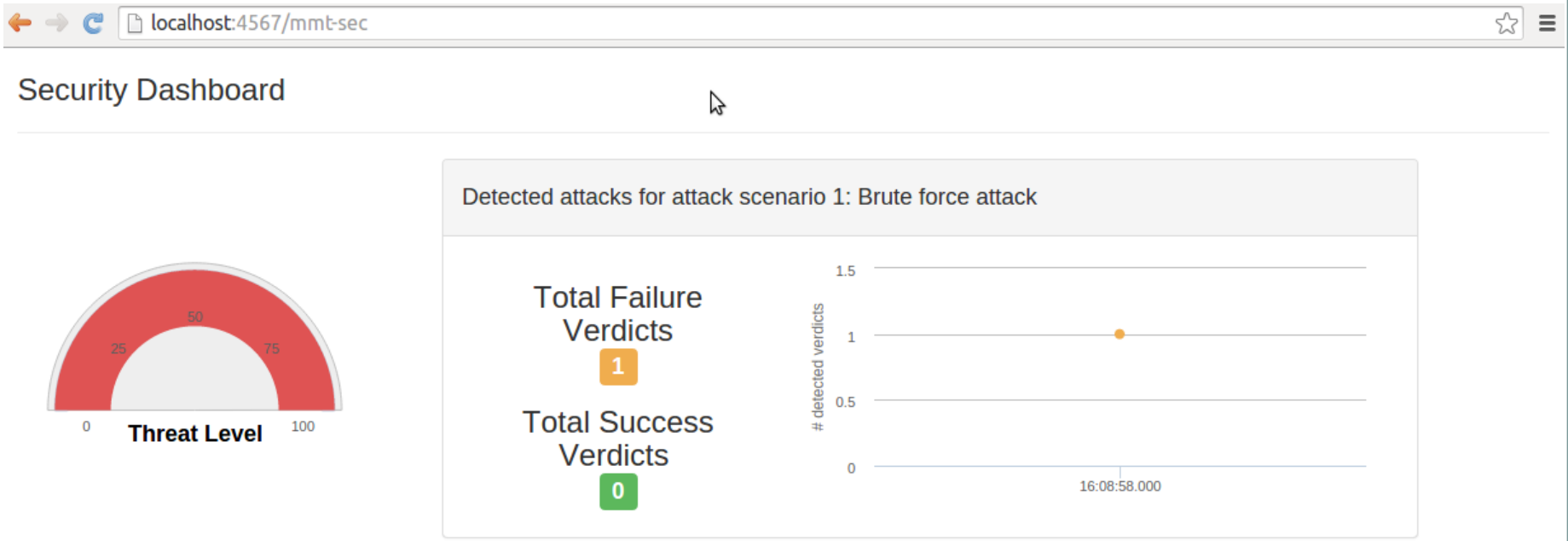
- Evoting test case – Advanced authentication option
  - Example of property: Only authenticated voters can cast their votes



MMT Analysis Dashboard- Security Property



MMT Analysis Dashboard-Attack Detection



Security rule	Description
R2= Permission(Org1, voter, access, L1, intranet_ context)	A voter connecting from the intranet system is permitted to access to the first type of election(named L1)
R3=Permission(Org1, voter, access, L2, intranet_ context)	A voter connecting from the intranet system is permitted to access to the second type of election(named L2)
R4=Permission(Org1, voter, access, L3, intranet_ context)	A voter connecting from the intranet system is permitted to access to the second type of election(named L3)
R5=Permission(Org1, voter, access, L5, desktop_ context)	A voter connecting from a specific desktop is permitted to access to the second type of election(named L4)
R6=Permission(Org1, voter, access, L4, desktop_ context)	A voter connecting from a specific desktop is permitted to access to athe second type of election(named L5)
R7=Obligation(Org1, server, authorize, Election_Lists, violation_context)	The server is authorized to check the elections lists when a violation is detected
R8=Obligation(Org1, voter, authenticate, L1, normal_context)	The voter should be authenticated to access to the first type of election (L1) when the normal context is activated (anonymous context is not activated).
R9=Obligation (Org1, voter, encrypt, L1_vote, violation_context)	The vote device should encrypt the data related to any election with the type L1 when a violation is detected.
R10=Obligation(Org1, voter, authenticate, L3, violation_context)	The voter should be authenticated to access to the third type of election (L3) when a violation is detected.
R11=Obligation(Org1, voter, Advanced_Authenticate, L4, normal_ context, violation_context)	The voter should be authenticated based on advanced methods to access to the third type of

Summary

- Model based test generation for security purposes (TestGen-IF)
- Correlation of data from different sources (Network, application, system)
- Detection of attacks and failures at runtime

  reaction
- Brings dynamicity to system by adapting to different contexts

Related Works

- Monitoring of routing protocols for ad hoc (OLSR protocol) and mesh networks networks based on a dsitributed approach (Batman protocol) (Telecom Sud Paris)
- Monitoring for secure interoperability – Application to a multi-source information system (Telecom Sud Paris)
- Monitoring with time constraints (C. Andrés, M. Nuñez and Mercedes Merayo)
- Monitoring with AsynchronousCommunications (M. Nuñez and R. Hierons)
- Other works by (T. Jeron and H. Marchand, A. Ulrich and A. Petrenko)

Conclusions

- It is now easier to support active testing and monitoring and integrate it with other development activities
- Modeling technology has matured (using FSMs, EFSMs, different UML profiles (SysML), temporal logics)
- Much research and innovation is still required and it should involve collaborations between research and industry

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