3rd UCAAT User Conference on Advanced Automated Testing

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SYSTEMATIC MODEL-BASED AND SEARCH-BASED TESTING OF CYBER-PHYSICAL SYSTEMS

Shaukat Ali, PhD, Senior Research Scientist

Email: shaukat@simula.no

[simula . research laboratory]

OUTLINE OF THE PRESENTATION

- Background
  - ✓Cyber-Physical Systems
  - ✓Search-based Software Engineering
- Results from previous projects
- Ongoing Project
- Summary, Experiences, and Lessons Learnt

BACKGROUND

Cyber-Physical Systems (CPS)

CYBER-PHYSICAL SYSTEMS

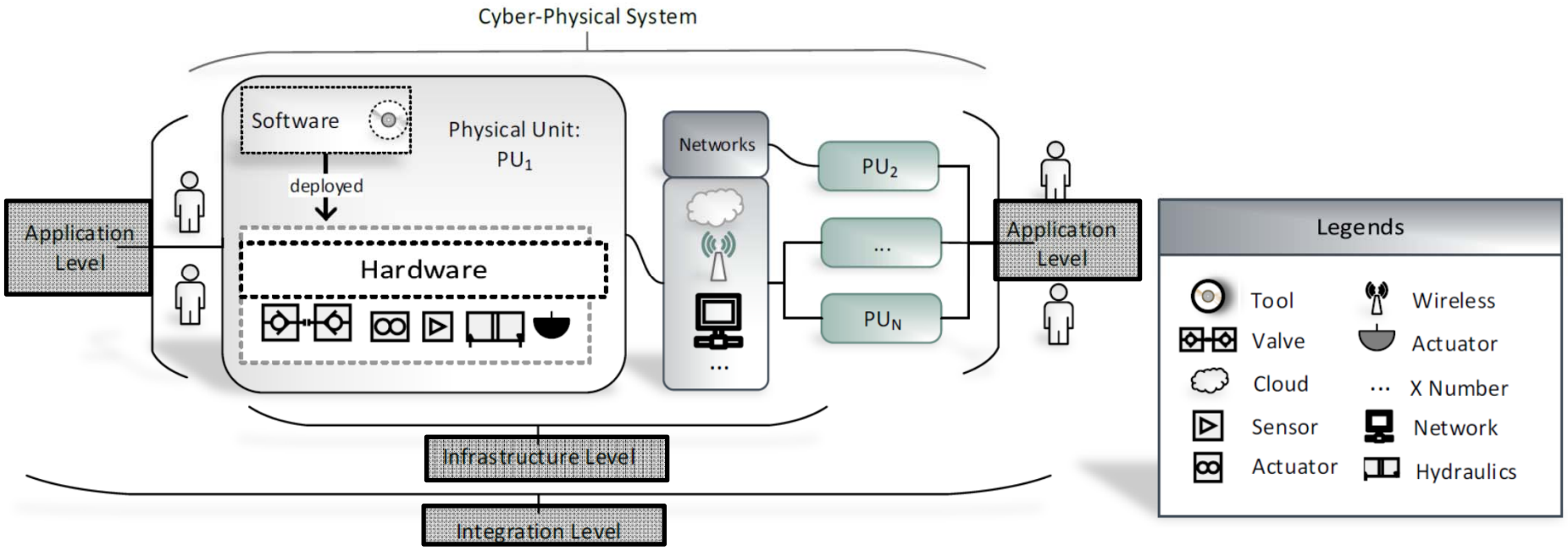
CPSs are the new generation of connected embedded systems integrating cyber-technologies, software, and physical components interacting with each other via information and physical interfaces [1].

Geo Sports: Picture courtesy
Future Position X, Sweden

Handling Systems: Picture courtesy
ULMA Handling Systems, Spain

[1] http://cyberphysicalsystems.org/

Testing Levels for CPS



Application Level : Events and data coming from the user space, e.g., from applications and human

Infrastructure Level : Events and data coming from, e.g., physical units, network equipment, and cloud infrastructure

Integration Level : Interactions between Application and Infrastructure levels

SCIENTIFIC AND TECHNICAL CHALLENGES

- Heterogeneous, Large-scale Embedded Systems
- Dealing with Novel Interactions
  - ✓Software, Hardware, Communication, Human
- Dealing with Uncertainty
- Verifying and validation of extra-functional properties such as performance, robustness, ..
- Autonomous

WHY IS IT IMPORTANT TO TEST CPS?

- Applications, e.g., Healthcare, Aerospace, Avionics, Oil/gas and Maritime, Industrial Automation, and Tele-communication
- Current applications > $32.3 trillions. By 2025, > $82 trillions [1].
- CPSs must be dependable, i.e., safe, trustworthy, reliable, robust, ...
- Improving CPS dependability via systematic and automated testing

[1] Evans, P.C., Annunziata, M.: Pushing the Boundaries of Minds and Machines. General Electric (GE), (2012)

BACKGROUND

SEARCH-BASED SOFTWARE ENGINEERING

Search-Based Software Engineering

"Using search techniques to search large search spaces, guided by a fitness function that captures properties of the acceptable software artifacts we seek"[1]

Search Techniques: Genetic Algorithms, Particle Swarm Optimization, …

Large Search Spaces: Millions or billions of possible solutions to search from.

Fitness Function: To determine solution *x* is *better* than Solution *y*.

[1] Borrowed from: SBSE: Introduction, Motivation, Results and Directions. Mark Harman Keynote at SSBSE, 2014

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RESULTS FROM SELECTED PROJECTS

ROBUSTNESS TESTING OF VIDEOCONFERENCING SYSTEMS

What is Robustness?

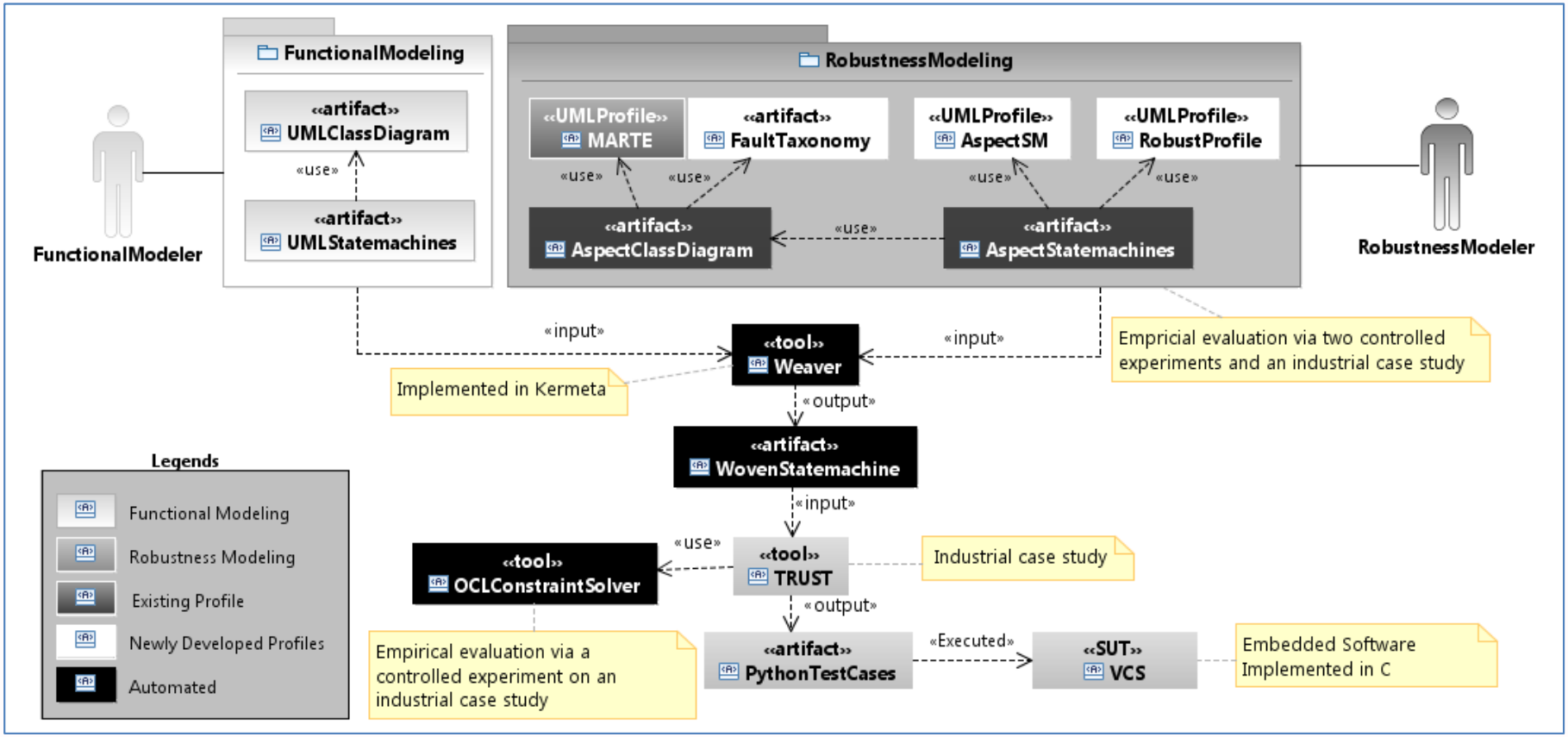
"Robustness is the degree to which a software component functions correctly in the presence of exceptional inputs *or stressful environmental conditions"* (IEEE Std 610.12-1990)

MODEL-BASED ROBUSTNESS TESTING IS CHALLENGING

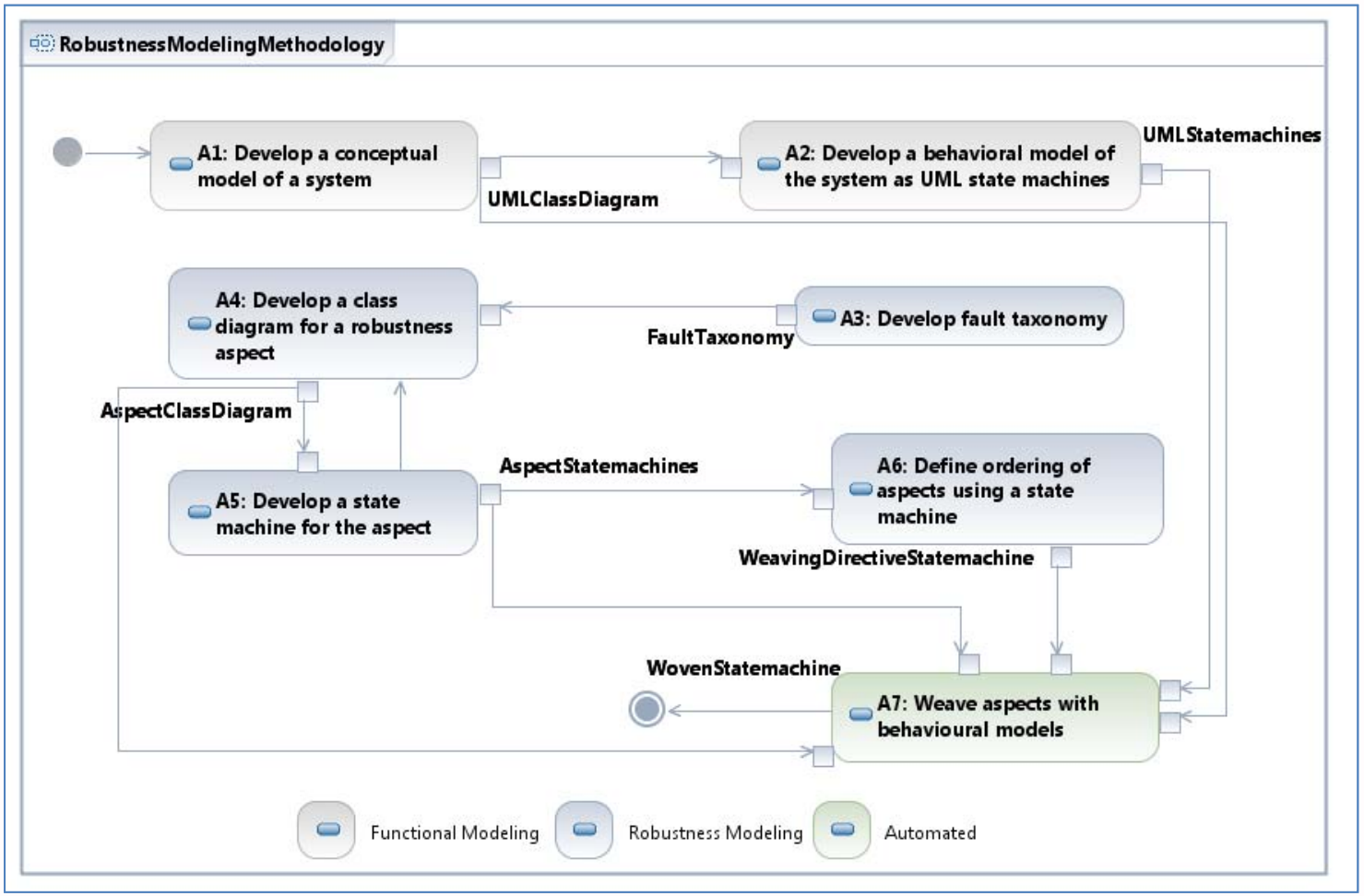
- Modeling robustness behavior makes modeling highly complex and redundant
- Automated generation of executable test cases from robustness models
  - ✓Targeted to reveal robustness faults
  - ✓Generating test data
  - ✓Defining appropriate test strategies for robustness testing

CASE STUDY:
VIDEOCONFERENCING SYSTEMS (CISCO)

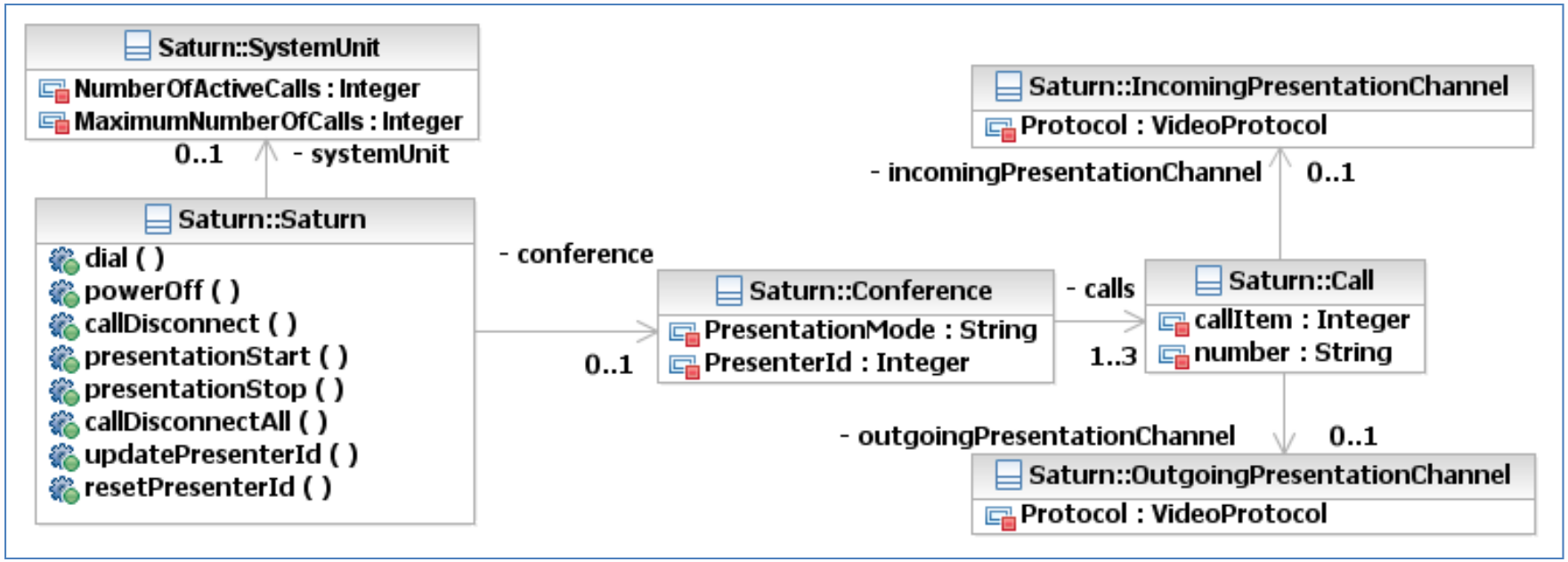
SOLUTION FOR MODEL-BASED ROBUSTNESS TESTING



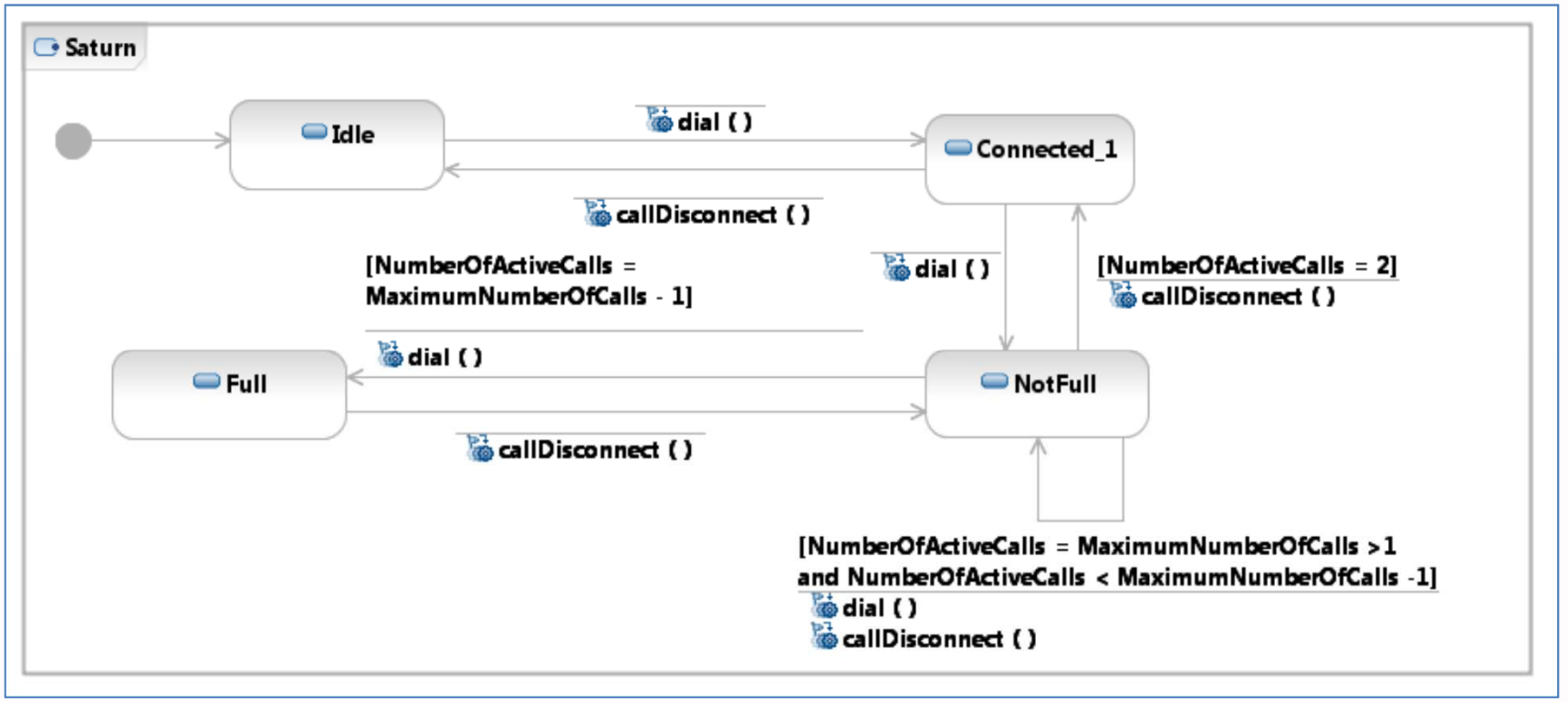
MODELLING METHODOLOGY



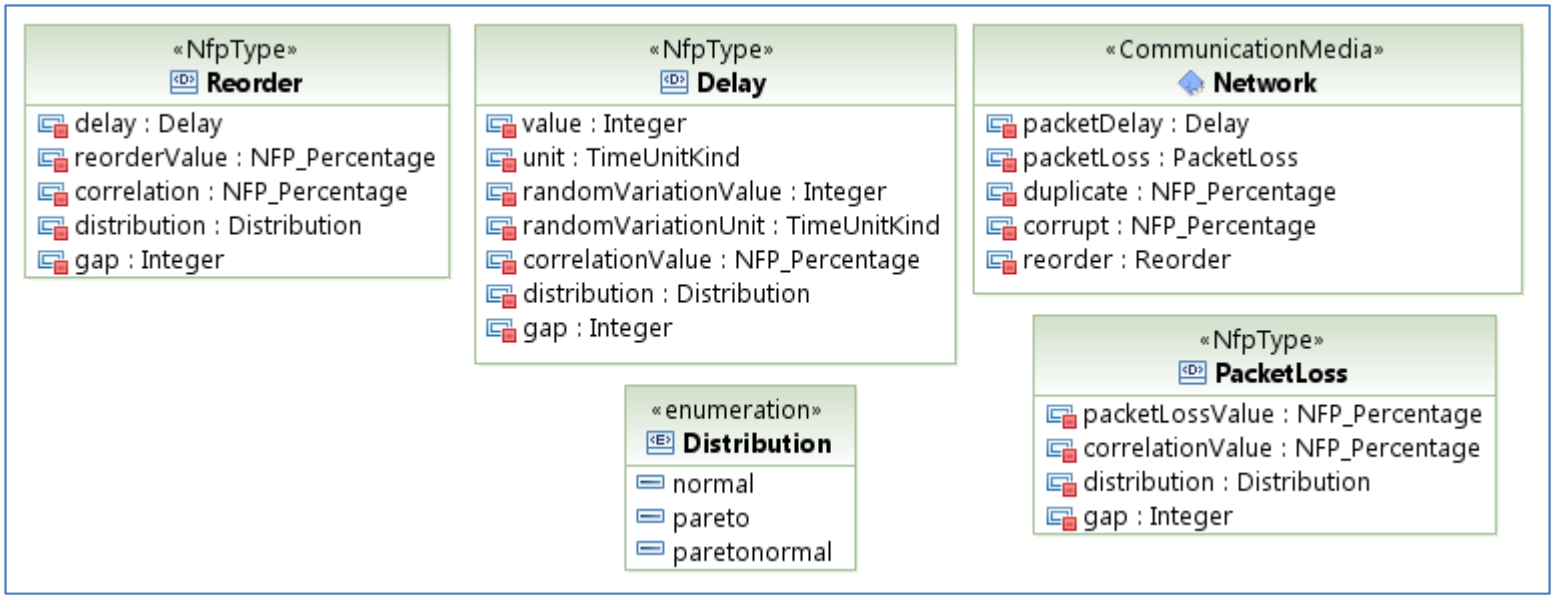
MODELING FUNCTIONAL BEHAVIOR



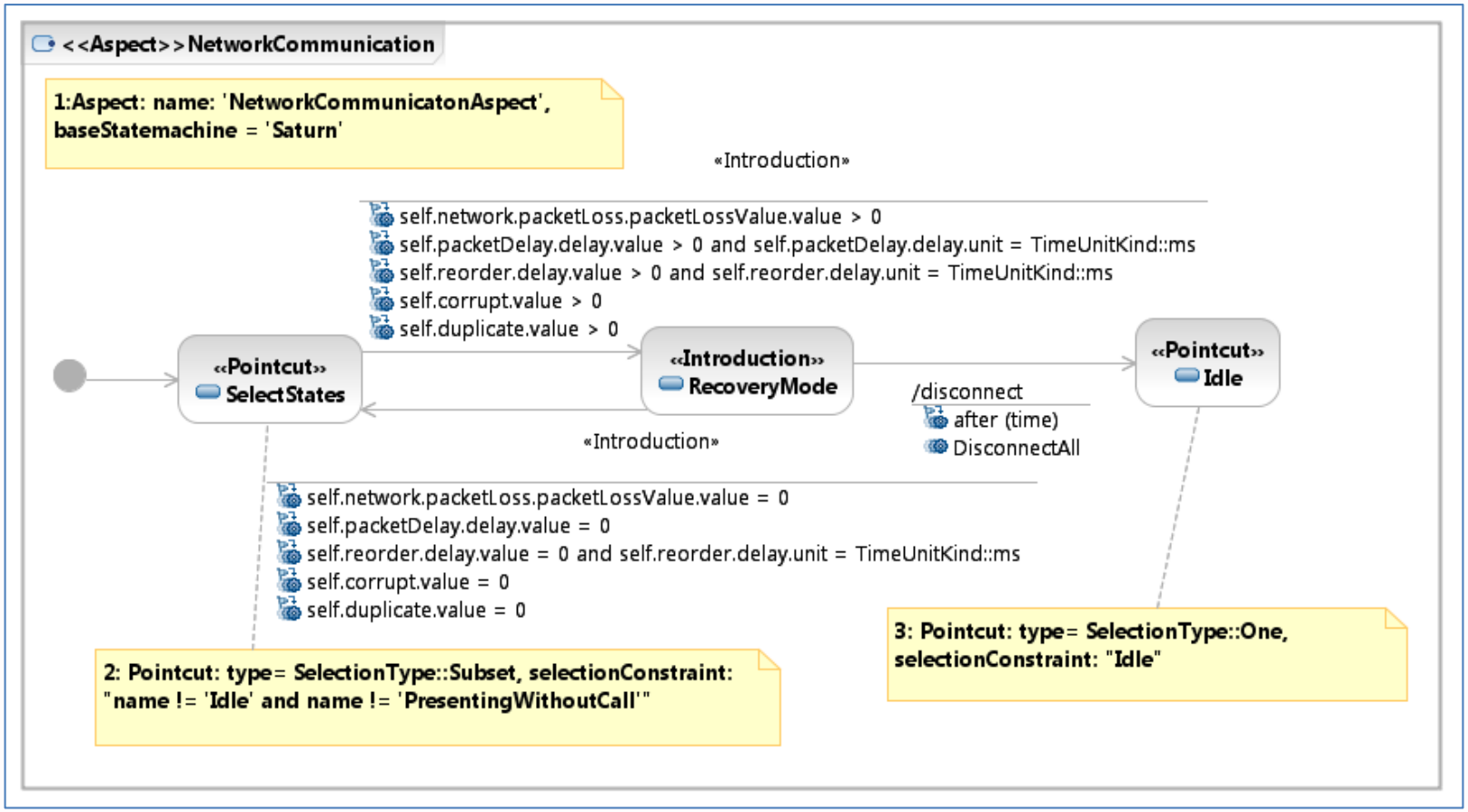
MODELING FUNCTIONAL BEHAVIOR



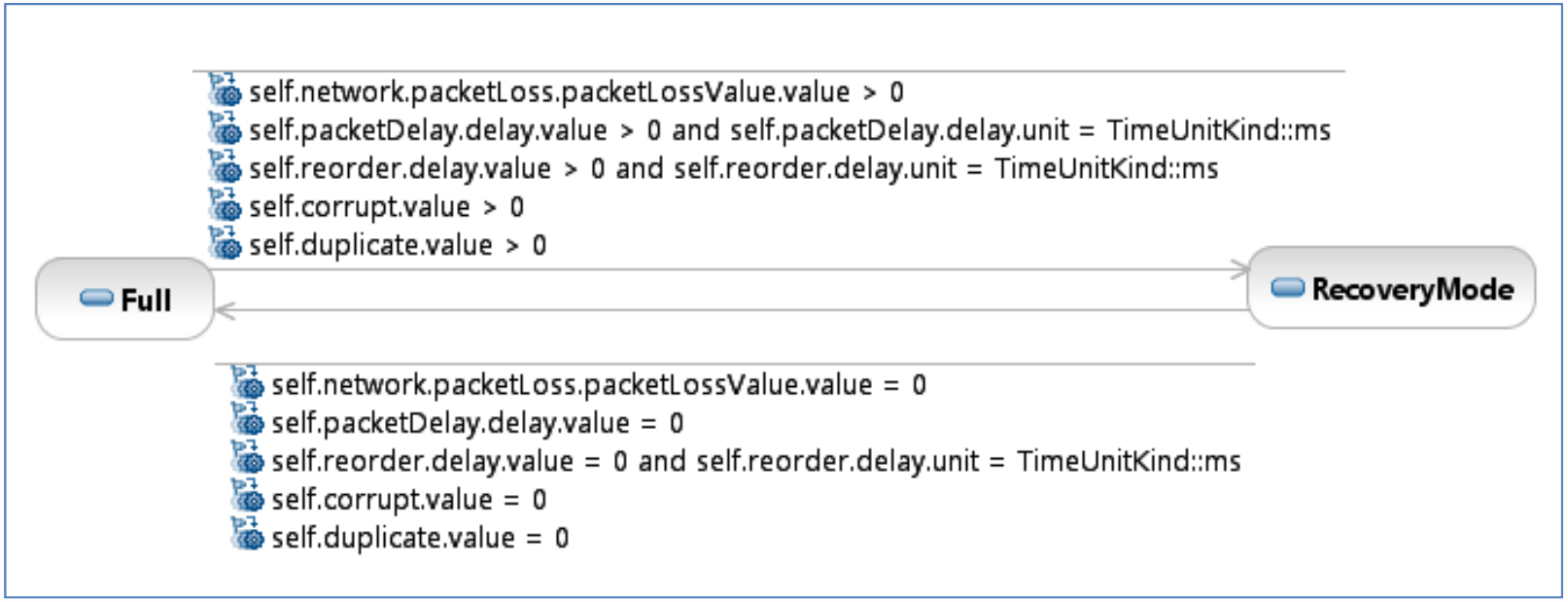
MODELING ASPECT CLASS DIAGRAM



MODELING ASPECT STATE MACHINES



WOVEN STATE MACHINE



RESULTS FROM MODELING

Crosscutting behavior	Using aspects			Without aspects			Effort Saved (%)		
	States (Added)	Transition (Added)	Trigger (Added)	States (Modified/Added)	Transitions (Modified/Added)	Trigger (Added)	States	Transitions	Trigger
Updating audio constraints	1	-	-	86 (Modified)	-	-	**98%**	-	-
Updating video constraints	1	-		86 (Modified)	-	-	**98%**	-	-
Media quality recovery	3	3	19	20 (Added)	178	1604	-	**98%**	**98%**
Network communication	3	3	13	20 (Added)	178	1082	-	**98%**	**98%**
Add Guard	2	1	-	0	22 (Modified)	-	-	**95%**	-

TEST CASE GENERATION

- Constraint solving using search algorithms for *Test Data Generation* (EsOCL tool)
  - ✓ Violates properties of the environment to check robustness of the system against those violations
  - ✓ Search algorithms such as GA, 1+1 (EA), ..
  - ✓ EsOCL's performance is practically applicable
- Developed a tool TRansformation-based tool for Uml-baSed Testing (TRUST)
  - ✓ Supports configurable and extensible features such as input models, test models, coverage criteria, test data generation strategies, and test script languages.
  - ✓ Applied to ABB Robotics and Cisco case studies

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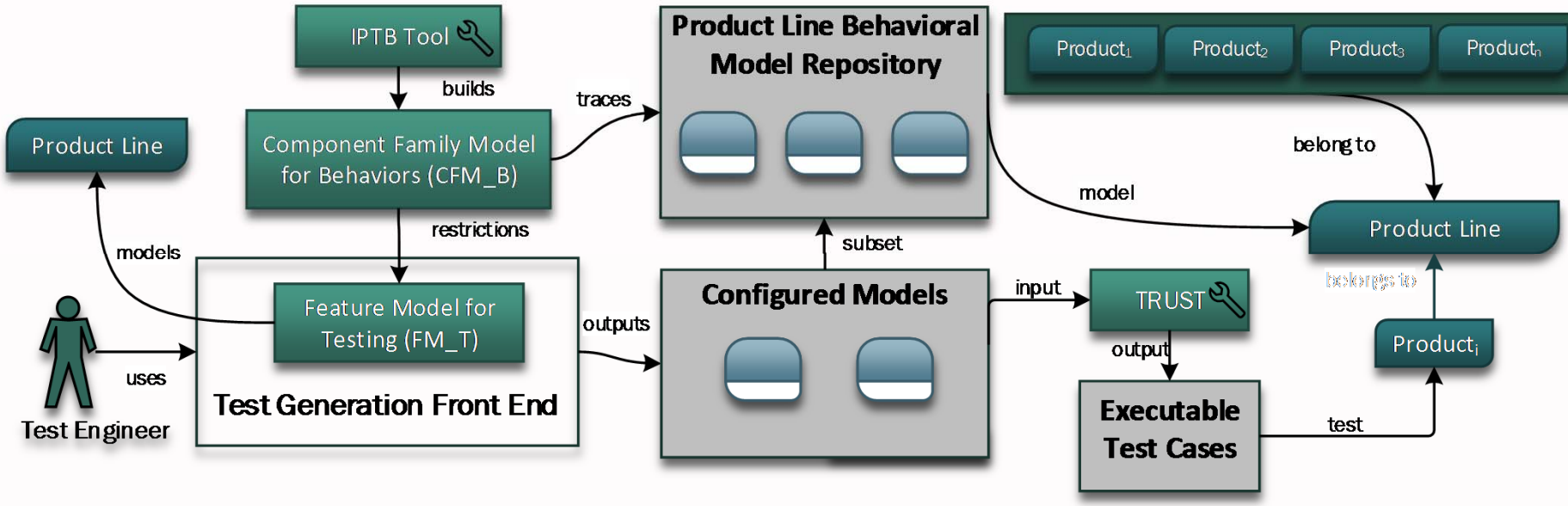
RESULTS FROM EXISTING PROJECTS

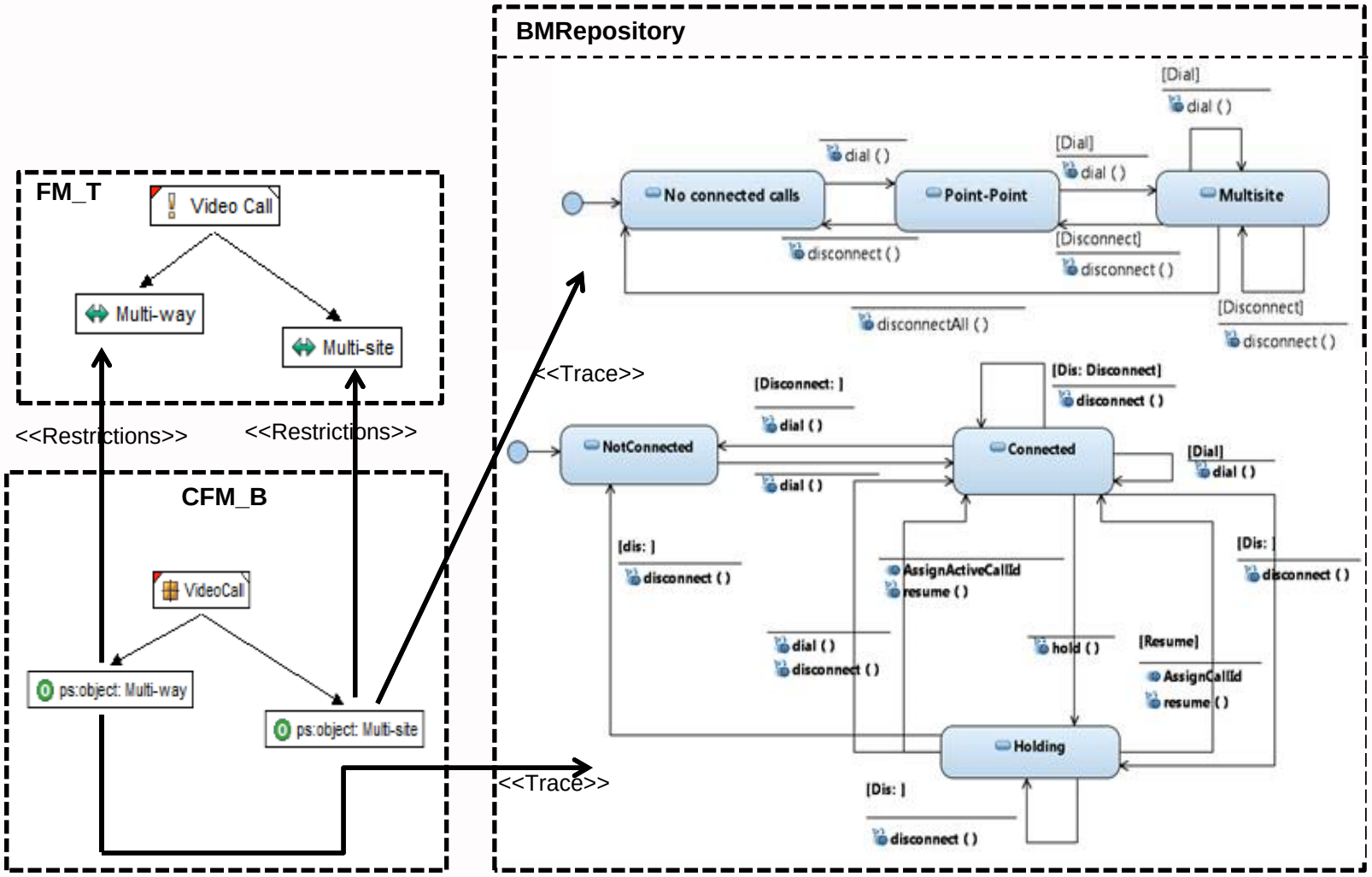
PRODUCT LINE TESTING

USING FEATURE MODELS TO SELECT AND CONFIGURE BEHAVIORAL MODELS

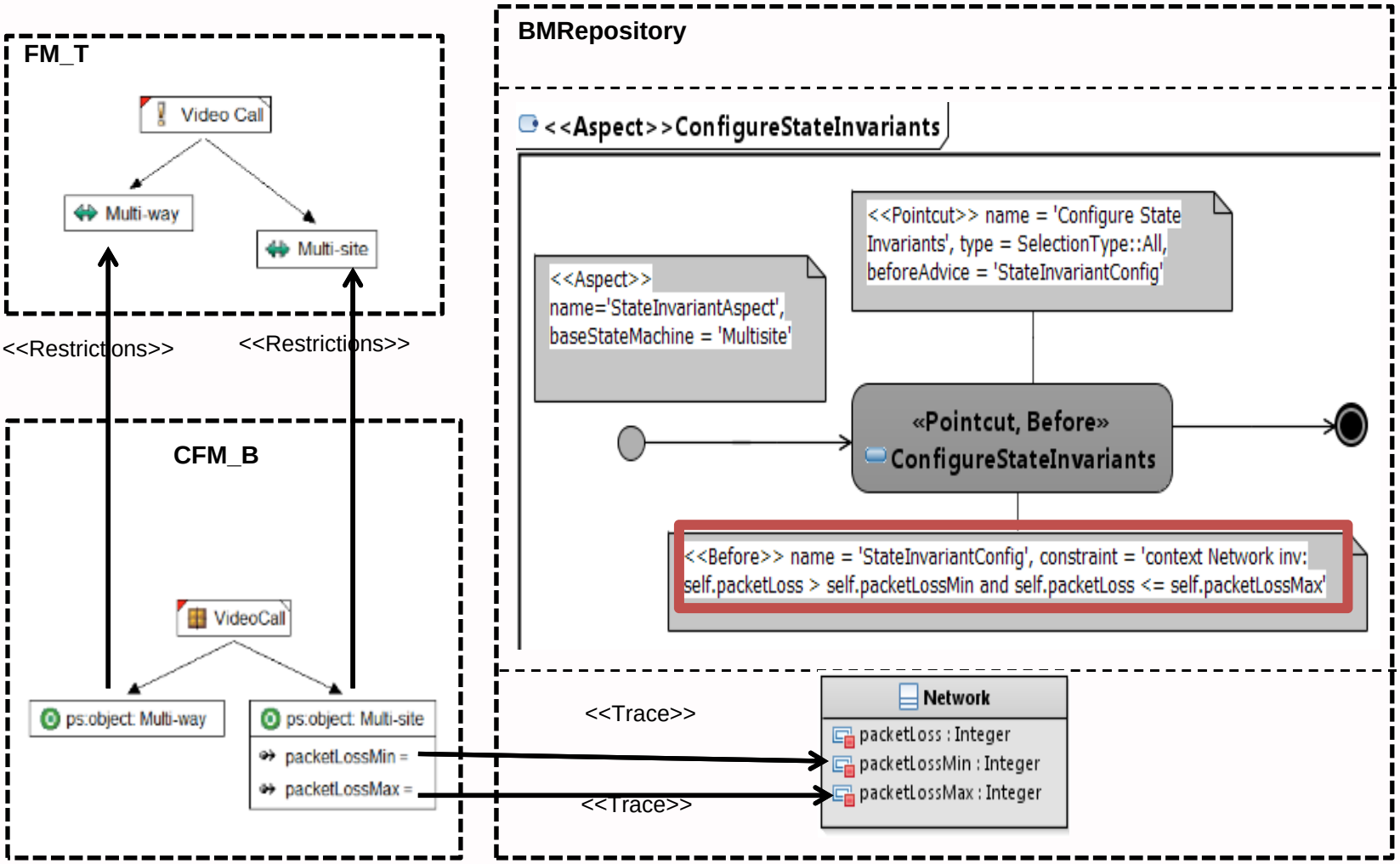


- Select features in FM_T through the Selection Front-end
- Configure attributes CFM_B through the Configuration Front-end

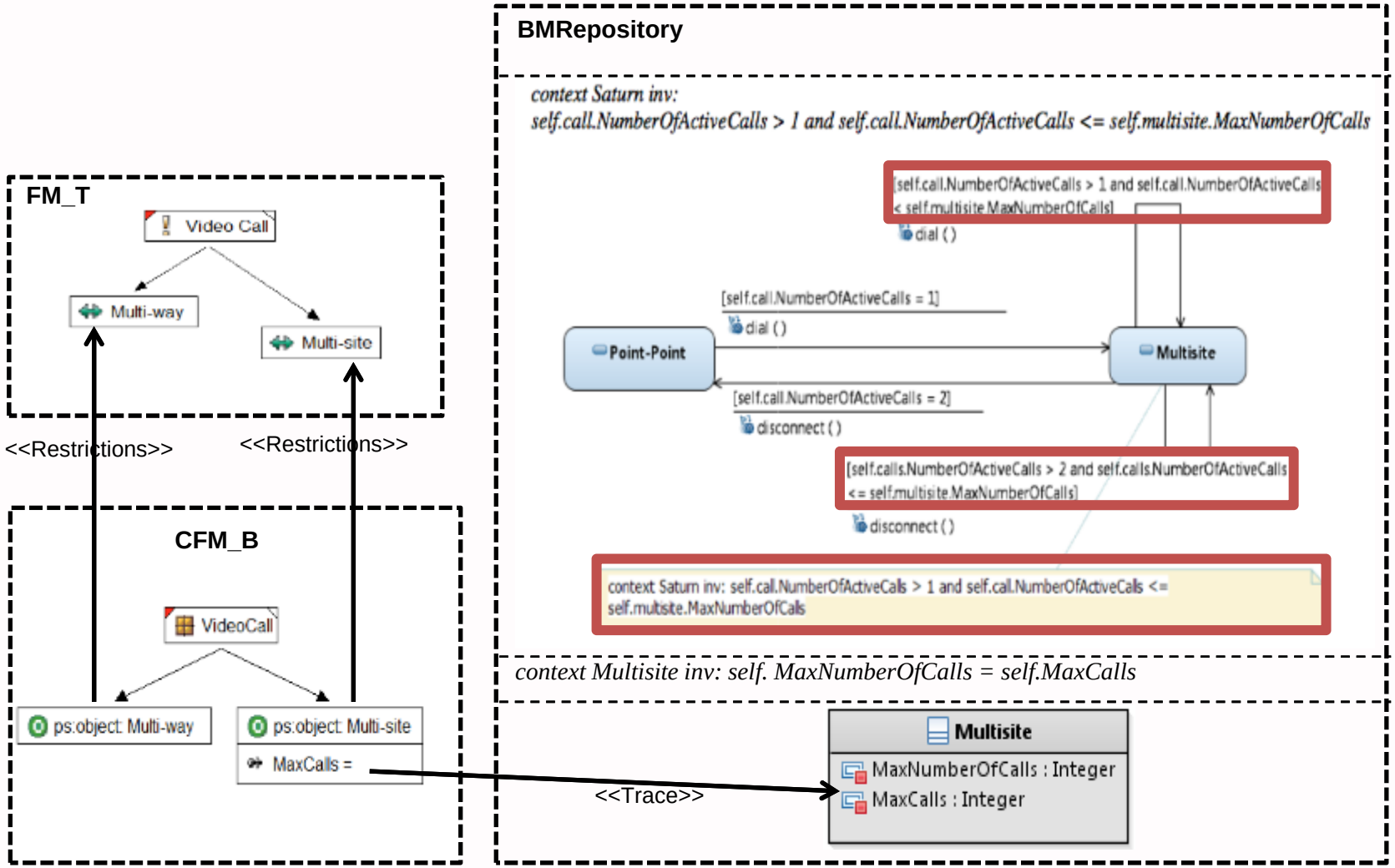
STATE MACHINE VARIABILITY



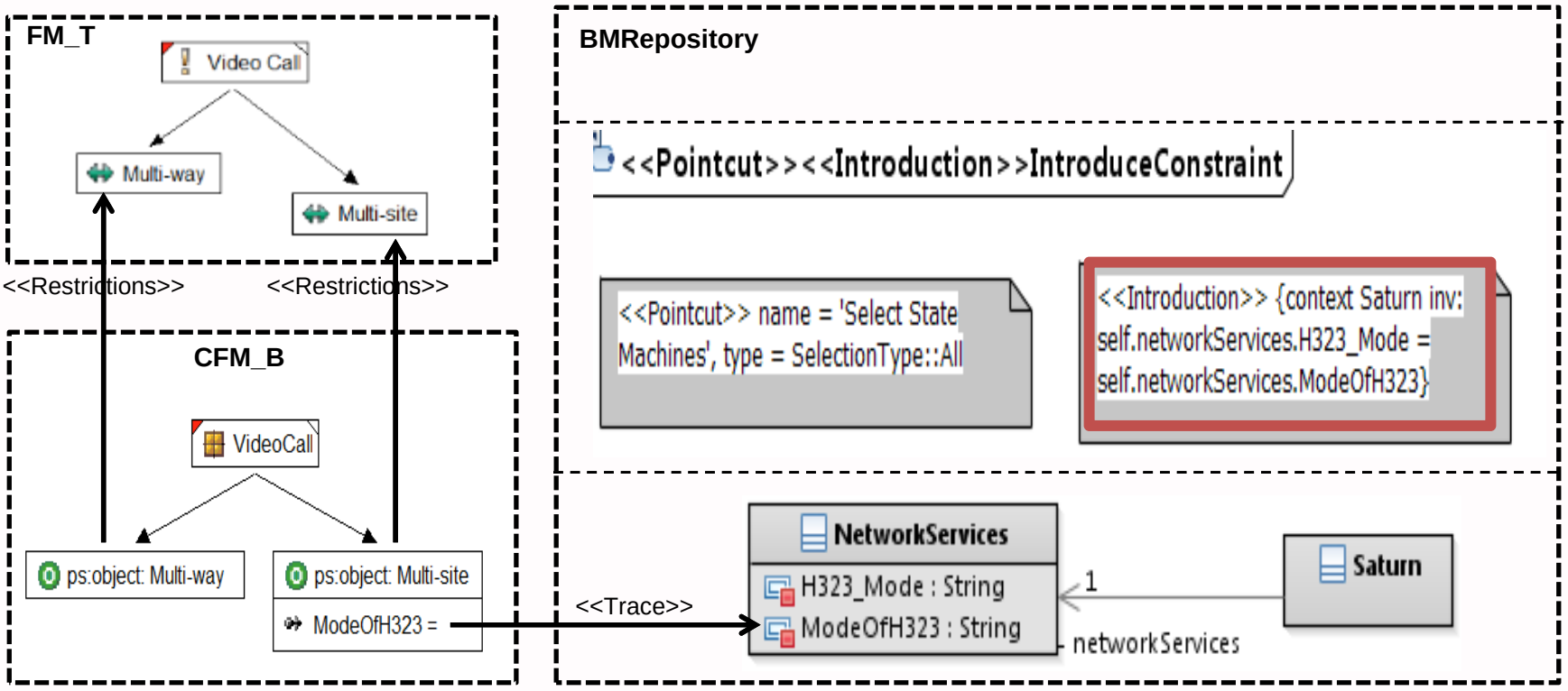
STATE MACHINE MODEL ELEMENT VARIABILITY



ATTRIBUTE VARIABILITY



ATTRIBUTE VARIABILITY



CONCLUDING REMARKS

- Applied to configure several products in a Videoconferencing Product Line of Cisco.
- The configured models were successfully used to generate test cases using TRUST.

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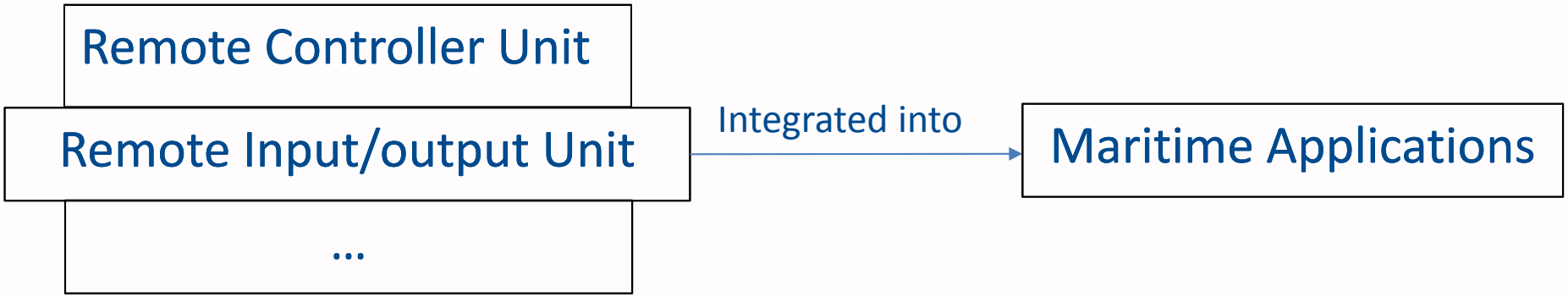
RESULTS FROM SELECTED PROJECTS

ROBUSTNESS TEST SELECTION IN A MARITIME APPLICATION

CONTEXT OF THE PROBLEM

- As part of a project in Certus [1] with Kongsberg Maritime as industrial partner
- Overall optimization objective is to find a set of test cases to “break” a CPS as soon as possible

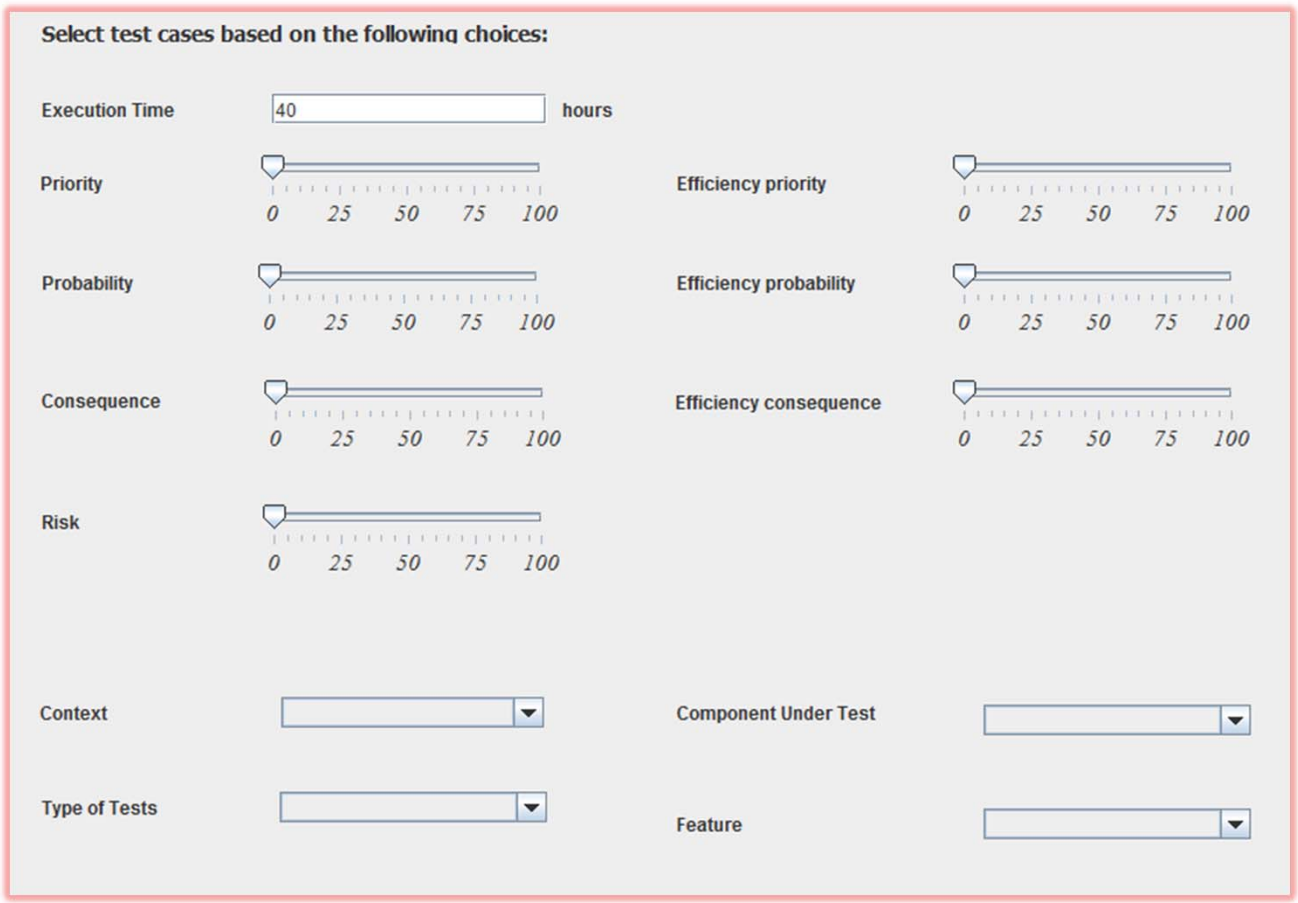


1. Certus Software Verification and Validation Center, http://certus-sfi.no/

OPTIMIZATION OBJECTIVES

- Input: Set of test cases focusing on testing software, hardware (mechanical, electronics, ..), interactions among them
- Cost
  - ✓Overall Execution Time,..
- Effectiveness
  - ✓Probability of Failure, Risk, Safety Level, …
- Fitness Function using Cost and Effectiveness measures
- Existing Implementation of Search Algorithms

TOOL SUPPORT



CONCLUDING REMARKS

- Some preliminary results are obtained.
- The tool seems to be promising based on initial experiments.
- More case studies are being conducted.

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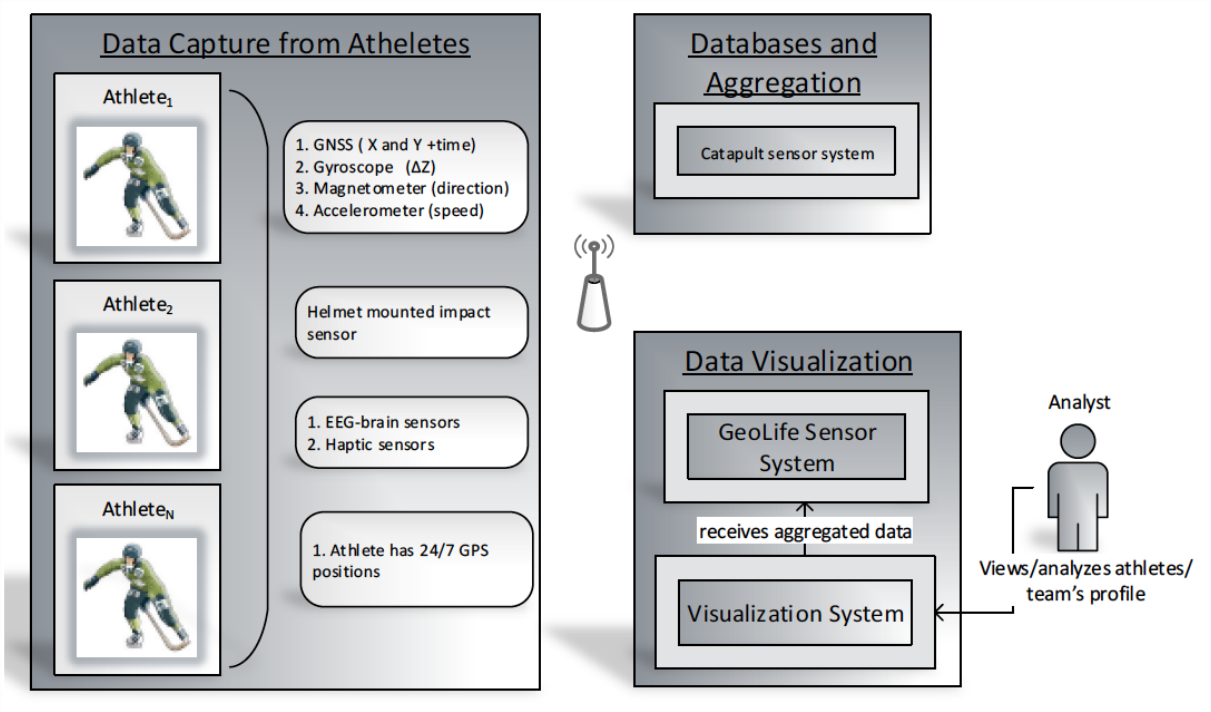
ONGOING CPS TESTING PROJECT: H2020

U-TEST: Testing Cyber-Physical Systems under Uncertainty: Systematic, Extensible, and Configurable Model-based and Search-based Testing Methodologies

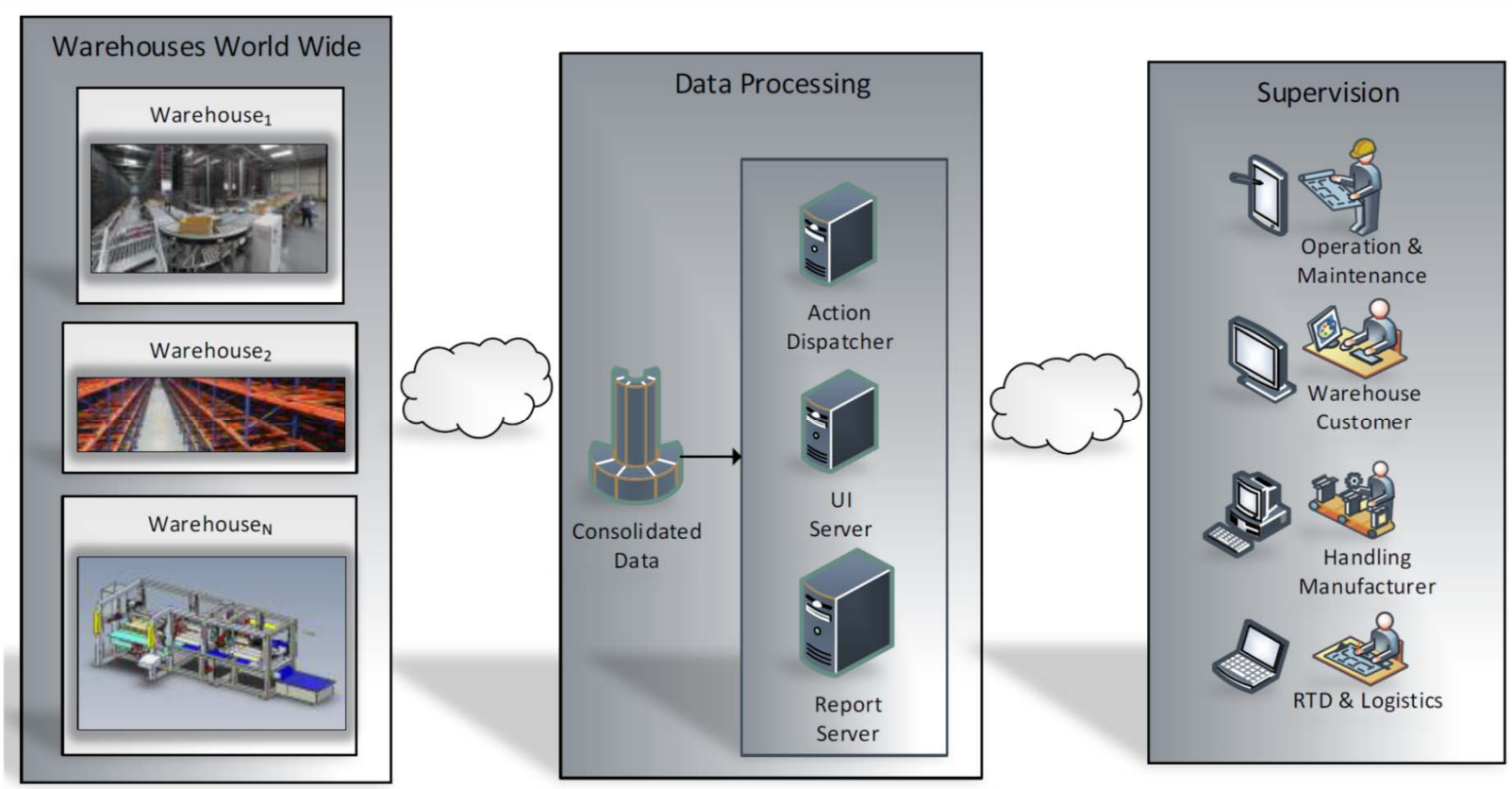
OBJECTIVES OF U-TEST

- **Objective:** Improve the dependability
- **Means:** Model-based and Search-based Testing
- Objective will be achieved by:
  - ✓Uncertainty Taxonomy
  - ✓Holistic Modeling and Testing Frameworks
  - ✓Standards

Case Study Providers: Geo Sports Future Position X, Sweden



Case Study Providers: Automated Warehouses ULMA Handling Systems, Spain



CONSORTIUM

- **Research Partners**
  - ✓ Simula Research Laboratory, Norway
  - ✓ Fraunhofer FOKUS, Germany
  - ✓ TU Wien, Austria
- **Tool Vendors**
  - ✓ Easy Global Marketing
  - ✓ FOKUS!MBT
- **Exploitation**
  - ✓ Ikerlan
- **Test Bed Provider**
  - ✓ Nordic MedTest
- **Project Management and Administration**
  - ✓ Oslo Medtech

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SUMMARY OF RESULTS

MODELING AND TESTING SOLUTIONS

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CPS MODELING FOR MBT

Category	Objective	Modeling Solution	CPS	Application
Robustness Testing	Test Case/Data Generation	UML Class Diagram, UML State Machine, AspectSM, and OCL	Video-Conferencing Systems Bottle Recycling System Ship Navigation System	Cisco Systems, Norway, Tomra, Norway WesternGeco, Norway
	Test Selection	UML Class Diagram and OCL	Dynamic Positioning Systems Vessel Control Systems	Kongsberg Maritime, Norway
Product Line Testing	Test Selection, Prioritization, Minimization	Feature Model Component Family Model	Video-Conferencing Systems	Cisco Systems, Norway
	Test Case/Data Generation	UML Class Diagram, UML State Machine, AspectSM, OCL and Feature Model		
Functional Testing	Test Case/Data Generation	RUCM, RTCM		

www.u-test.eu

Experiences

Modeling Objective	Modeling Solutions
Requirements Specification, V&V	RUCM, RUCM4RT, RTCM, AspectRUCM, RUCM Variability, **RUCM4Uncertainty**
CPS Product Line Engineering	UML, OCL, MARTE, the SimPL Profile
Model Based Testing	UML, OCL, MARTE, the AspectSM Profile
Model Based Uncertainty Testing	UML, OCL, MARTE, SysML, **the Uncertainty Profile**
Model Based Product Line Testing	Feature Model, UML, the AspectSM Profile

Experiences:

- Largely relied on standards
- Proposed several profiles for various purposes
- Developed our own NL-based and model-based solutions
- Developed tools
- Intentionally made effort to reduce modeling effort
- Evaluated with controlled experiments and industrial case studies
- Used existing search algorithms and in rare cases extended

Lessons Learnt

Modeling Objective	Modeling Solutions
Requirements Specification, V&V	RUCM, RUCM4RT, RTCM, AspectRUCM, RUCM Variability, **RUCM4Uncertainty**
CPS Product Line Engineering	UML, OCL, MARTE, the SimPL Profile
Model Based Testing	UML, OCL, MARTE, the AspectSM Profile
Model Based Uncertainty Testing	UML, OCL, MARTE, SysML, **the Uncertainty Profile**
Model Based Product Line Testing	Feature Model, UML, the AspectSM Profile

Lessons Learnt:

- Poor capability of integrating methodologies and tools
- Difficult to think systematically since the beginning
  - ✓ Uncertainty taxonomy
- Always a challenge to evaluate a modeling methodology
  - ✓ Expressiveness, Usability, Applicability, Readability, etc.
- Which search algorithm to use in which situation
  - ✓ Large scale experiments to select algorithms for different situations

Acknowledgements

- Tao Yue, Shuai Wang, Bran Selic
- Man Zhang
- Former Colleagues: Lionel Briand, Andrea Arcuri, Hadi Hemmati, Zohaib Iqbal, Nina Holt

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Questions