[simula . research laboratory]
- by thinking constantly about it

TESTING CYBER-PHYSICAL SYSTEMS IN UNCERTAINTY

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IEEE ICOSST-2016, Lahore, Pakistan

MY RESEARCH

- ✓Verification and Validation of Software-Intensive Systems
- Cyber-Physical Systems (CPSs)
- Techniques & Methods
  - Modeling
  - Search-Based Software Engineering
- Empirical Evaluation

MY BACKGROUND

- **Industry Background**
  - ✓ More than 10 years of industrial experience in the domains of Maritime, Oil and Gas, Tele-communication, Logistics, and Healthcare
- **Academic Profile**
  - ✓ **50+** publications in top conferences and journals in the last **4** years
  - ✓ Technical Manager for an on-going EU project (Current Presentation)
  - ✓ PI/CO-PI of several other local and international projects

U-Test is a EU-funded H2020 project (2015 Jan. – 2017 Dec.)

TESTING CYBER-PHYSICAL SYSTEMS UNDER UNCERTAINTY
Website: http://www.u-test.eu
Overall Funding: 3.71 Million Euros
Duration: 2015 to 2018
Partners: 9
Technical Coordinator: Shaukat Ali

We are going beyond the scope of this project and establishing a long-term, industry-oriented research foundation towards this direction.

CYBER-PHYSICAL SYSTEMS (CPS)

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].

Car Sports Picture courtesy Future Position X, Sweden

Handling Systems Picture courtesy ULMA Handling Systems, Spain

[1] http://cyberphysicalsystems.org/

CYBER-PHYSICAL SYSTEM: SOFTWARE, HARDWARE (MECHANICS, ELECTRONICS, …), COMMUNICATION

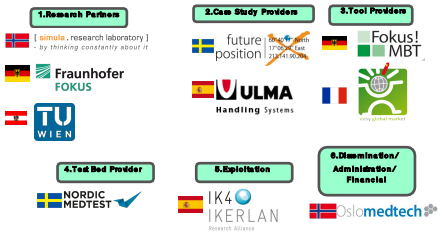
- Applications, e.g., **Healthcare**, Aerospace, **Avionics**, **Oil/gas, Maritime**, **Industrial Automation**, and **Tele-communication**
- Applications > **$32 trillions** and expects to grow > **$82 trillions** by 2025
- Enormous dependence of our lives on CPSs in the future
- CPSs must be dependable.
- Improving CPSs' dependability via systematic and automated testing

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

UNCERTAINTY IS INHERENT IN CPS

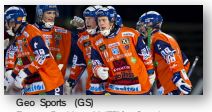
- Operate in highly **unpredictable** environment or even **unknown** environment
- Internal behaviour of a CPS may be **unknown**
- Uncertainty in the behaviour
- Uncertainty in the environment
- Uncertainty in the interactions between a CPS and its environment

U-Test consortium: 9 partners



Two industrial CPSs

Automated Warehouse (AW)
ULMA Handling Systems, Spain



Geo Sports (GS)
Future Position X (FPX), Sweden

http://www.u-test.eu/use-cases/

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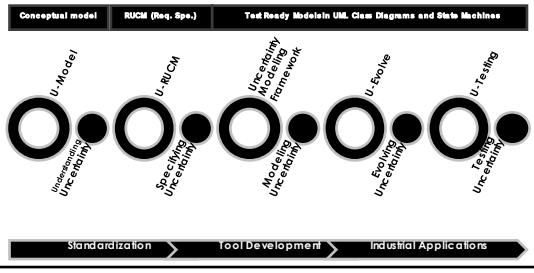
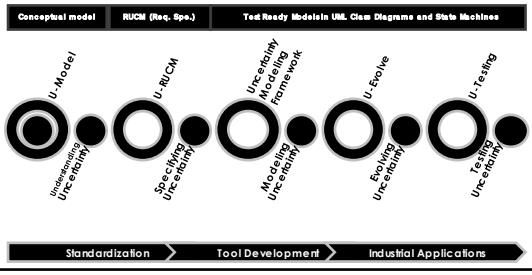
Overall Roadmap



Overall Roadmap



U-Model: A *generic* and *subjective* uncertainty conceptual model

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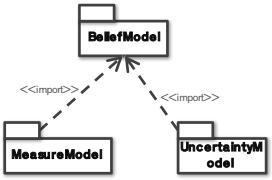
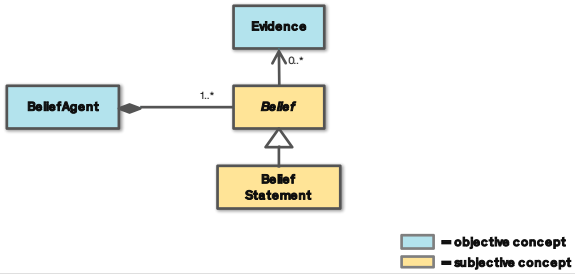
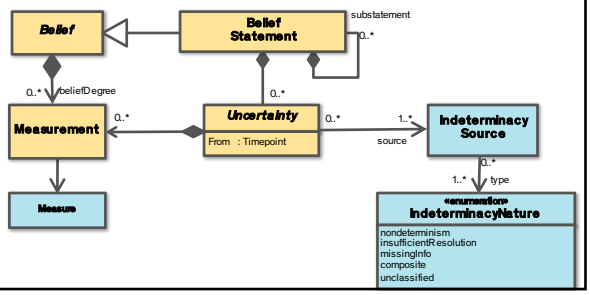
The U-Model takes a *subjective* approach to represent uncertainty!



Belief model – Belief



Belief model– Uncertainty



U-Model was further extended for supporting model-based testing (**MBT**) of all the three levels of **CPS** (i.e., **Application**, **Infrastructure** and **Integration**) under uncertainty.

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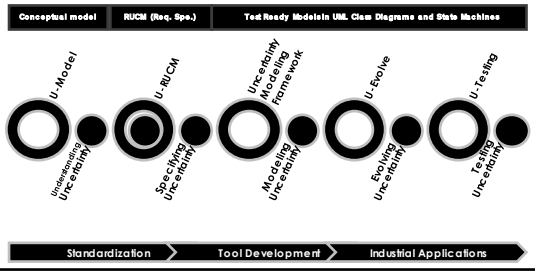
Overall Roadmap



U-RUCM: Specifying uncertainty requirements as use case models

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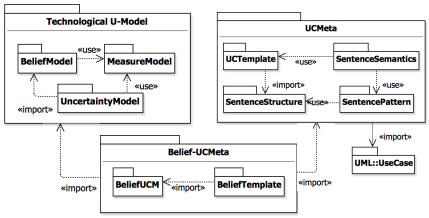
U-RUCM integrates U-Model and RUCM.



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Specify uncertainty with U-RUCM in industry settings

- U-RUCM was able to **significantly improve on characterization,** and **understanding of uncertainty** requirements.
- Key experience
  - ✓ Learn about uncertainty by applying U-RUCM
  - ✓ Systematically **discover unknown known indeterminacy sources and uncertainties** and **transforming them into known unknown uncertainties and known known indeterminacy sources**.

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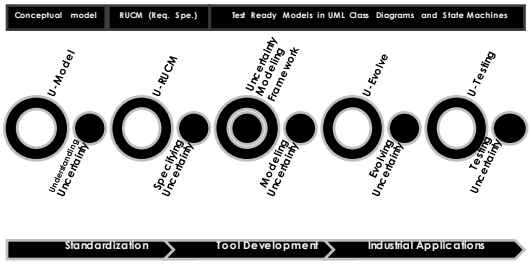
Overall Roadmap



UMF: Uncertainty Modeling Framework

An integrated modeling framework to facilitate **MBT** of **CPS** under **Uncertainty**

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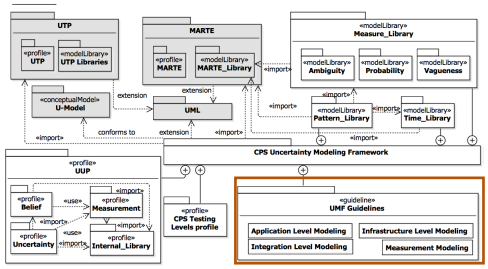
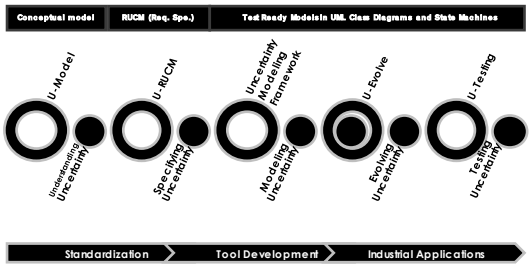
UMF is a comprehensive UML-based modeling solution.



UMF was evaluated with two industrial case studies and one extended open source one!

- Case studies
  - Video conferencing systems from Cisco, Norway.
  - GeoSports from Future Position X, Sweden.
  - SafeHome
- To check the correctness of the test ready models against collected (uncertainty) requirements, we relied on simulation using executable UML.
  - Identified 56 problems across the three case studies.
- UMF is **not** for supporting modeling of CPS and uncertainty from the design and development perspectives.

Overall Roadmap



U-Evolve: Evolving UMF Test Ready Models with Uncertainty for Testing CPS

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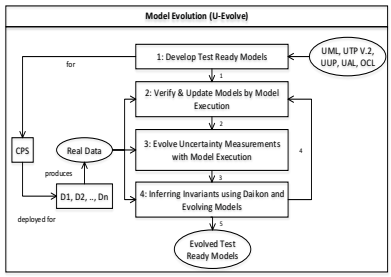
Key steps



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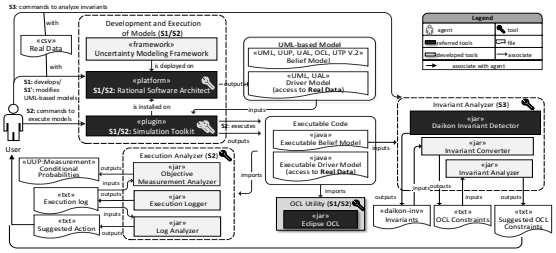
U-evolve is an integration of tools.



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Evaluation

- Case study
  - ✓ GeoSports from FPX, Sweden
- Results
  - ✓ Evolved 51% of belief elements, 18% of states, and 21% of transitions as compared to the initial test ready model.
- Discussion
  - ✓ More case studies are definitely required.
  - ✓ Use the same case study with additional real data.
  - ✓ Extensive empirical studies are ongoing.

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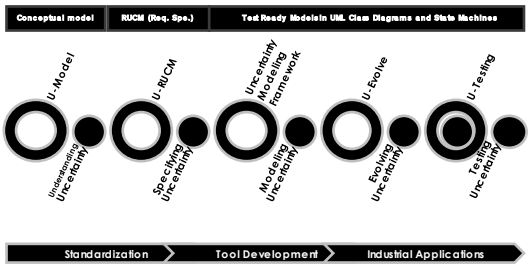
Overall Roadmap



U-Testing: Uncertainty-based Test Case Generation and Minimization for CPS

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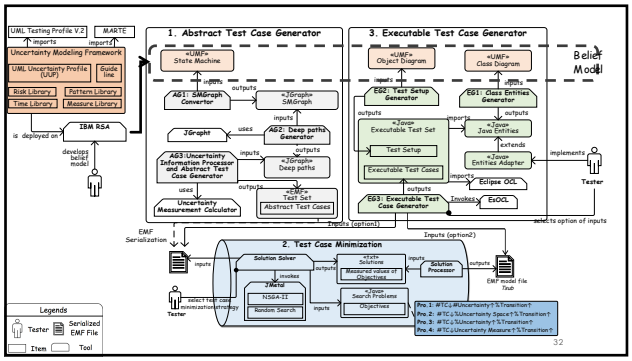

INTEGRATING MBT, UNCERTAINTY THEORY, AND MULTI-OBJECTIVE SEARCH

Test Case Generation
- All Simple Path
- All Paths with Fixed Max. Length

Test Case Minimization
Uncertainty Related Objectives **(Uncertainty theory)**
- Max. the number of uncertainties
- Max. the number of unique uncertainties
- Max. the subjective confidence (uncertainty measure)
- Min. the uncertainty space
- Min. the number of test cases
- Max. the transition average

Test Case Execution
- Mutation Testing
- Real Case Study

Execution with introduced indeterminacy Source

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ALL STRATEGIES ARE EVALUATED IN TERMS OF **COST, EFFECTIVENESS, AND EFFICIENCY**.

Test Case Generation → **Test Case Minimization** → **Test Case Execution**

Safe Home

	#TC		#Min. TC	%Min.	Mutation Score	Efficiency $\frac{\text{mutation score}}{PTM}$	Efficiency $\frac{\#\text{ of mutants killed}}{\text{time for executing test cases}}$
APL	2		-		8.9%		
APML	1253	#Uncertainty	490	60%	100%	2.5	0.06
		Uncertainty Space	136	80%	98%	8.8	0.22
		Uncertainty Measure	490	60%	100%	2.5	0.06
		Unique Uncertainties	109	91%	100%	11.2	0.27

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WE APPLY THE BEST STRATEGY TO TEST THE REAL CASE STUDY IN TERMS OF DISCOVERING UNCERTAINTIES.

Test Case Generation → **Test Case Minimization** → **Test Case Execution**

GeoSports

	#TC		#Min. TC	%Min.	Observed Uncertainty	New Uncertainty
APML	2085	Unique Uncertainties	336	83.9%	98	18

- Test infrastructures have been built, which enable the **introduction of known indeterminacy sources**.
  - Signal Shielding box and Far From Locator
  - **Unknown Indeterminacy sources**

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Foster long-term and community-wide benefits through standardization

- Uncertainty Modeling
  - ✓ Initiated the standardization process in June 2016
  - ✓ **Uncertainty RFI** is officially issued in Sep. 2016
  - ✓ Call for responses until Feb. 2017.
  - ✓ http://www.omgwiki.org/uncertainty/doku.php
- SysML V2 RFP Working Group
  - ✓ Latest version is SysML 1.4.
  - ✓ Contributing to the Requirement Concepts Modeling Focus Team
    - Restricted Requirements Statements and Uncertainty Requirements
  - ✓ http://www.omgwiki.org/OMGSysML/doku.php?id=sysml-roadmaprequirement_concepts_modeling_core_team
- UML Testing Profile V2
  - ✓ http://utp.omg.org/
  - ✓ http://zen-tools.com/utp/

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A lot of work to be done in the future.

- Empirical studies on U-RUCM, U-Evolve and U-Testing.
- More realizations of U-Model.
- Other applications, e.g., IoT, Self-adaptive Systems.
- How about industrial?
  - ✓ Tools, standards, training, culture…
- Deep uncertainty?

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ACKNOWLEDGEMENT






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