



DISCOVERING AND TESTING UNKNOWN UNCERTAINTIES OF CYBER-PHYSICAL SYSTEMS

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Recognized challenges of uncertainty

- In 1986 (30 years ago),
 - ✓ Bon K. Sy and Martin E. Kaliski published an abstract at CSC'86
 - “An Uncertainty-based Software Testing Model Using Test Universe Partitions (Abstract)”
- In 1997 (almost 20 years ago),
 - ✓ Ziv Hadar, Richardson Debra, Klosch Rene submitted a paper to ICSE'97
 - “The Uncertainty Principle in Software Engineering”

Edward A. Lee said at MODELS 2016:

“CPS applications operate in an intrinsically **nondeterministic** world.”

”**Deterministic models aren’t always possible or practical** due to complexity, **unknowns**, chaos, and incompleteness.”



Lionel Briand said at ICSE 2016, V2025:

“...**models** necessarily have **uncertainties** due to complex, dynamic environment behaviors and the unknowns about the system. This makes it crucial for **model testing to be uncertainty-aware**”.



David S. Rosenblum said at ASE 2016, FSE 2014 and NASAC 2013:

Software systems increasingly exhibit many kinds of uncertainty. **Uncertainty greatly complicates testing.**



What does SIEMENS say?

Testing based on **non-deterministic** choice of behavior and data proved very successful.



EMBRACING NON-DETERMINISM IN TESTING

Andreas Ulrich, Stefan Dorsch

SIEMENS

Bran Selic says:

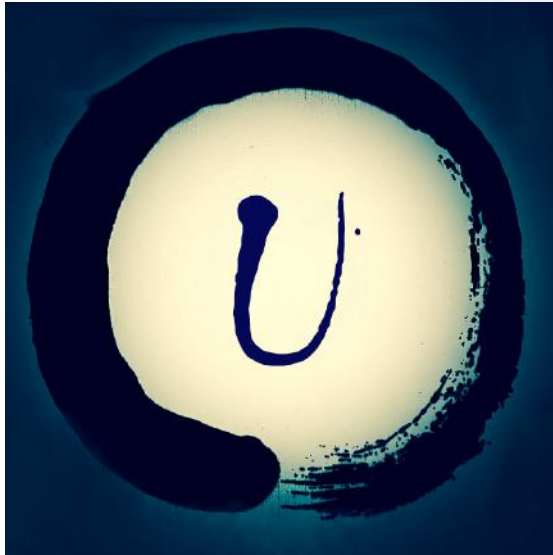
Uncertainty is the Elephant in the Room!

常常被视而不见。



We need to recognize new reality and **embrace uncertainty** as a first-order design concern!

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

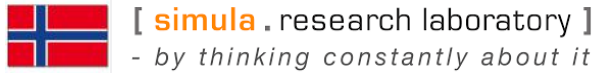
Partners: 9



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

U-Test consortium: 9 partners

1. Research Partners



4. Test Bed Provider



2. Case Study Providers



5. Exploitation



3. Tool Providers



6. Dissemination/ Administration/ Financial



Two industrial CPS



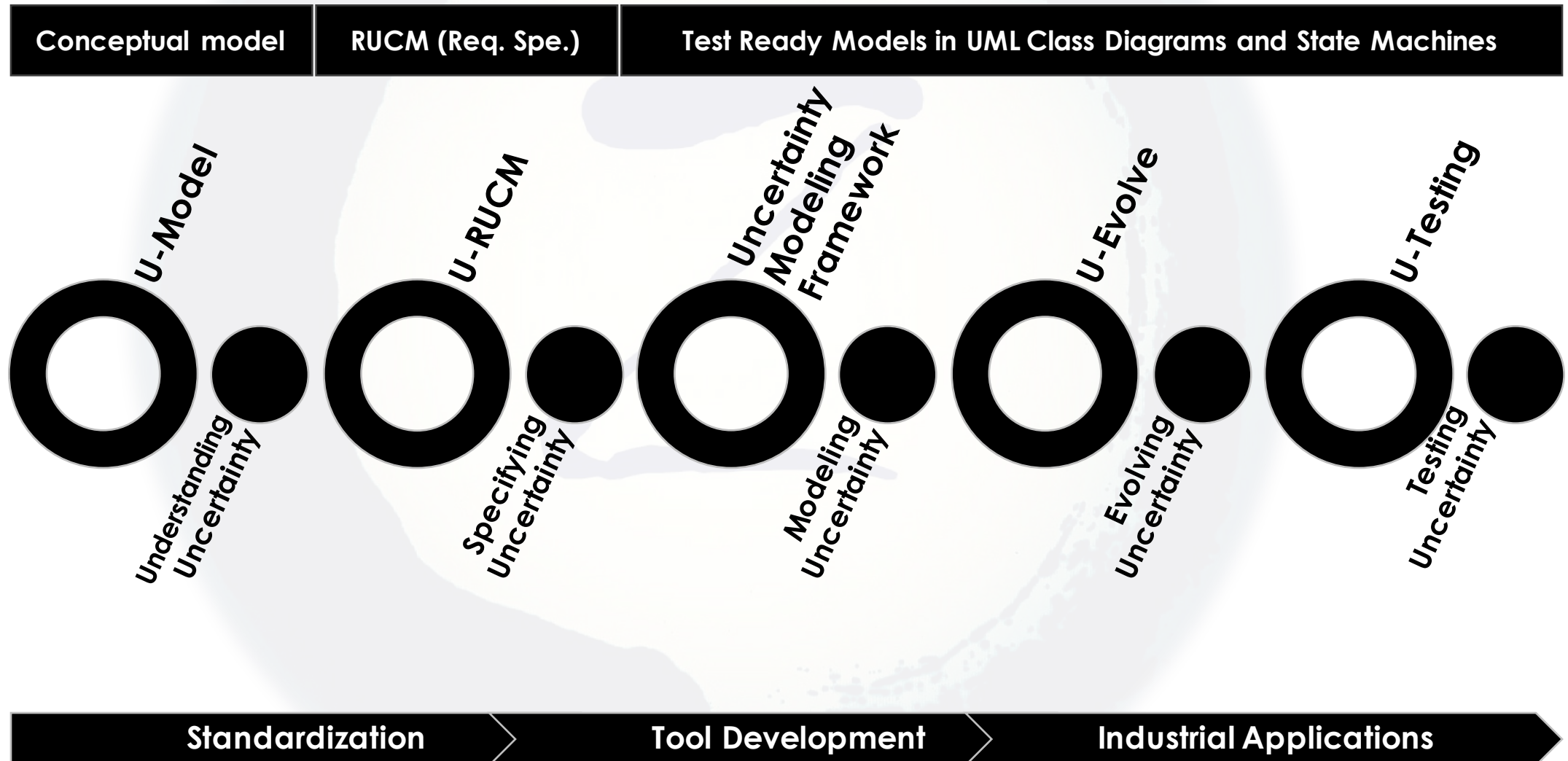
Automated Warehouse (AW)
ULMA Handling Systems, Spain



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

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

Our attempt is just the tip of the iceberg (冰山一角).

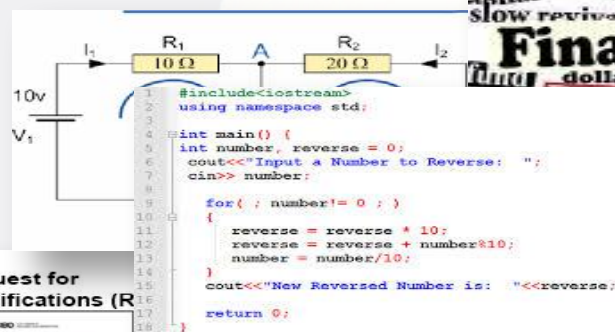




U-Model: *A generic and subjective*
uncertainty conceptual model

Complex system design...

- ...requires knowledge of many different things...



Request for

Qualifications (R)

USISO 9001:2015 ISO 9001:2015 CONFORMANT

Document 80204 - 2018 2018 12/31/2020

Quality Management System

The National Fire Protection Association

USISO 9001:2015 ISO 9001:2015 CONFORMANT

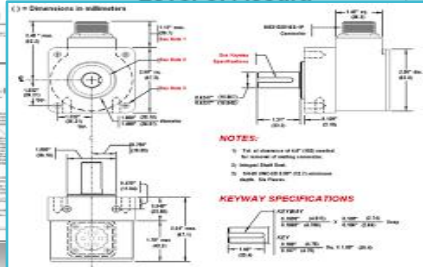
Document 80204 - 2018 2018 12/31/2020

Quality Management System

United States Fire Protection Association

3D Imaging Specification

Level of Accuracy

[illegible]

$$\begin{aligned} Y(X) &= \sum_i P(x_i) H(Y|x_i) \\ &= - \sum_i P(x_i) \sum_j P(y_j|x_i) \log P(y_j|x_i) \\ &= - \sum_{i,j} P(x_i \cdot y_j) \log P(y_j|x_i) \\ &= - \sum_{i,j} P(x_i \cdot y_j) \log P(x_i \cdot y_j) + \sum_{i,j} P(x_i \cdot y_j) \log P(x_i) \\ &= H(X, Y) - H(X) \end{aligned}$$

Law Changes

W to comply

Compliance Rules

How rules affect you

UNIFIED
MODELING
LANGUAGE

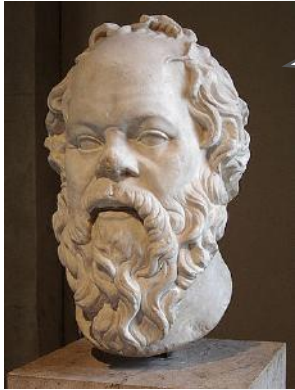


Complex system design...

- ...requires knowledge of many different things...



But, what is “knowledge”?

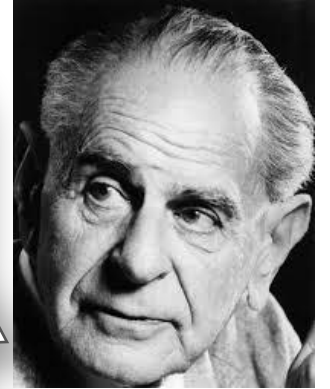


SOCRATES (470-399 BC)
苏格拉底

“I know that I know nothing”
我知道我什么都不知道。

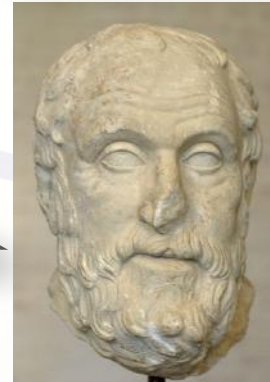
Knowledge is, irreducibly conjectural or hypothetical, generated by creative imagination

知识是不可简化的推测或假设，通过创造性的想象力产生。



K. POPPER (1902-1994)
卡尔·波普尔

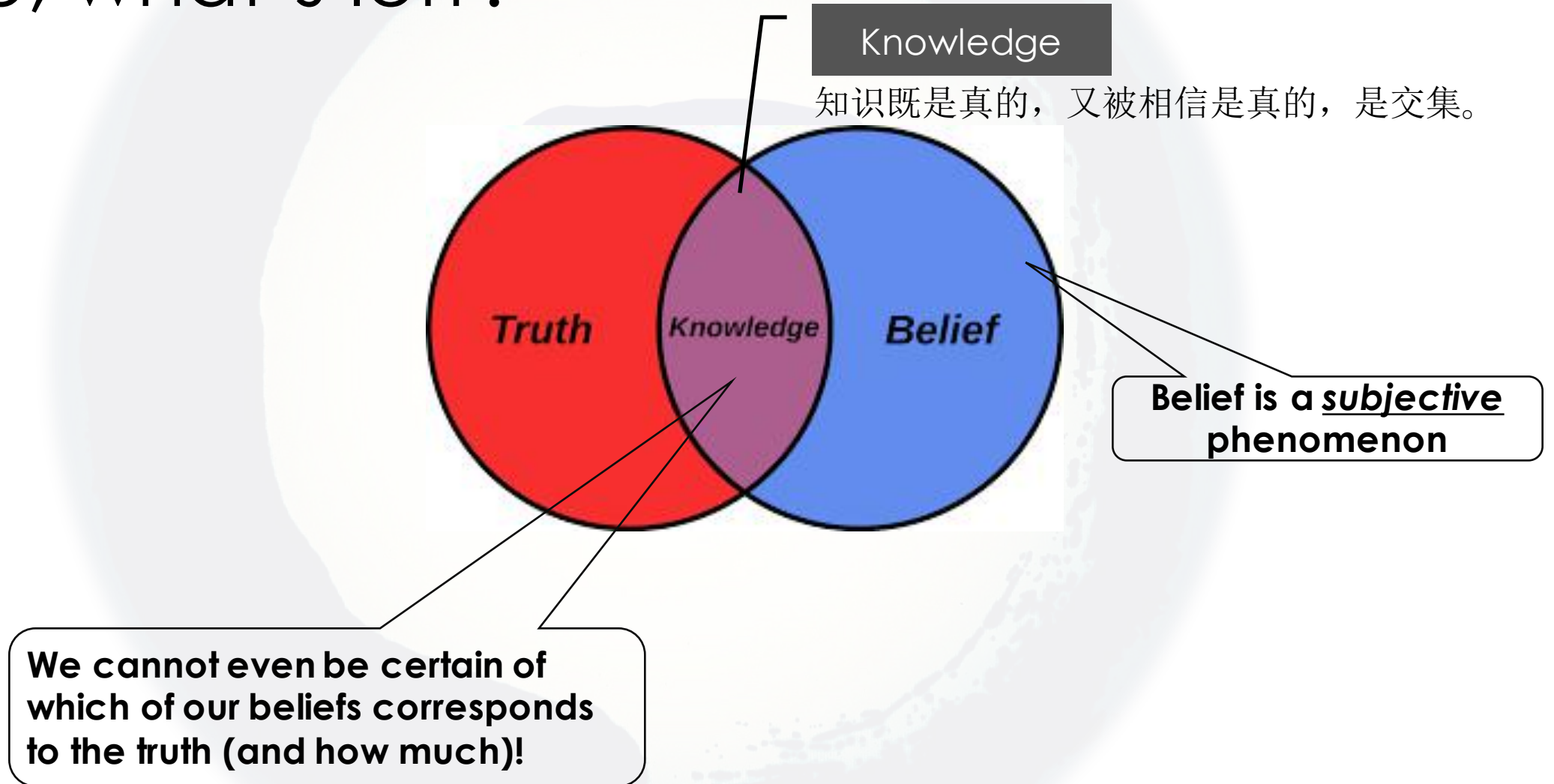
“Nothing can be known – not even this”
没有什么事情是已知的。



CARNEADES (213-129 BC)
卡尔内阿德斯

Knowledge is an elusive and controversial concept.

So, what's left?



An important distinction

- **Objective**

- ✓ Refers to phenomena or concepts whose existence and nature are independent of any observing agency

- **Subjective**

- ✓ Refers to information existing within some agency derived from observation and/or reasoning by that agency
- ✓ ...which leads us to belief

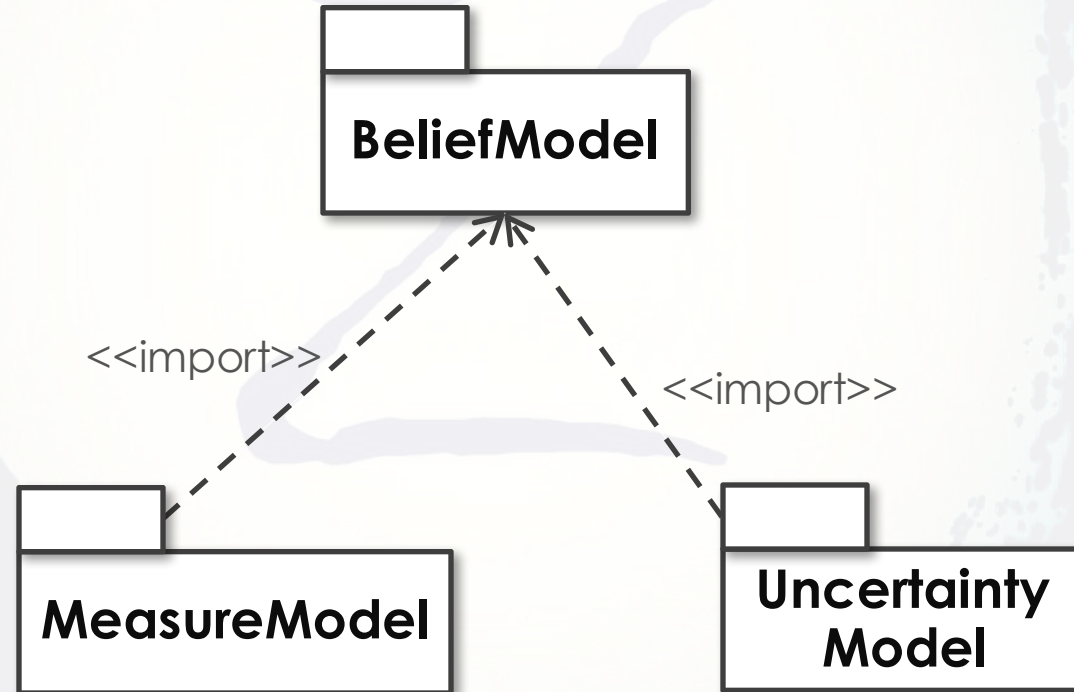
The objective and the subjective

- What is the elephant?
- Who are the blind men?
- Each statement is based on concrete evidence.
- Each statement is **a belief statement** of a belief agent.

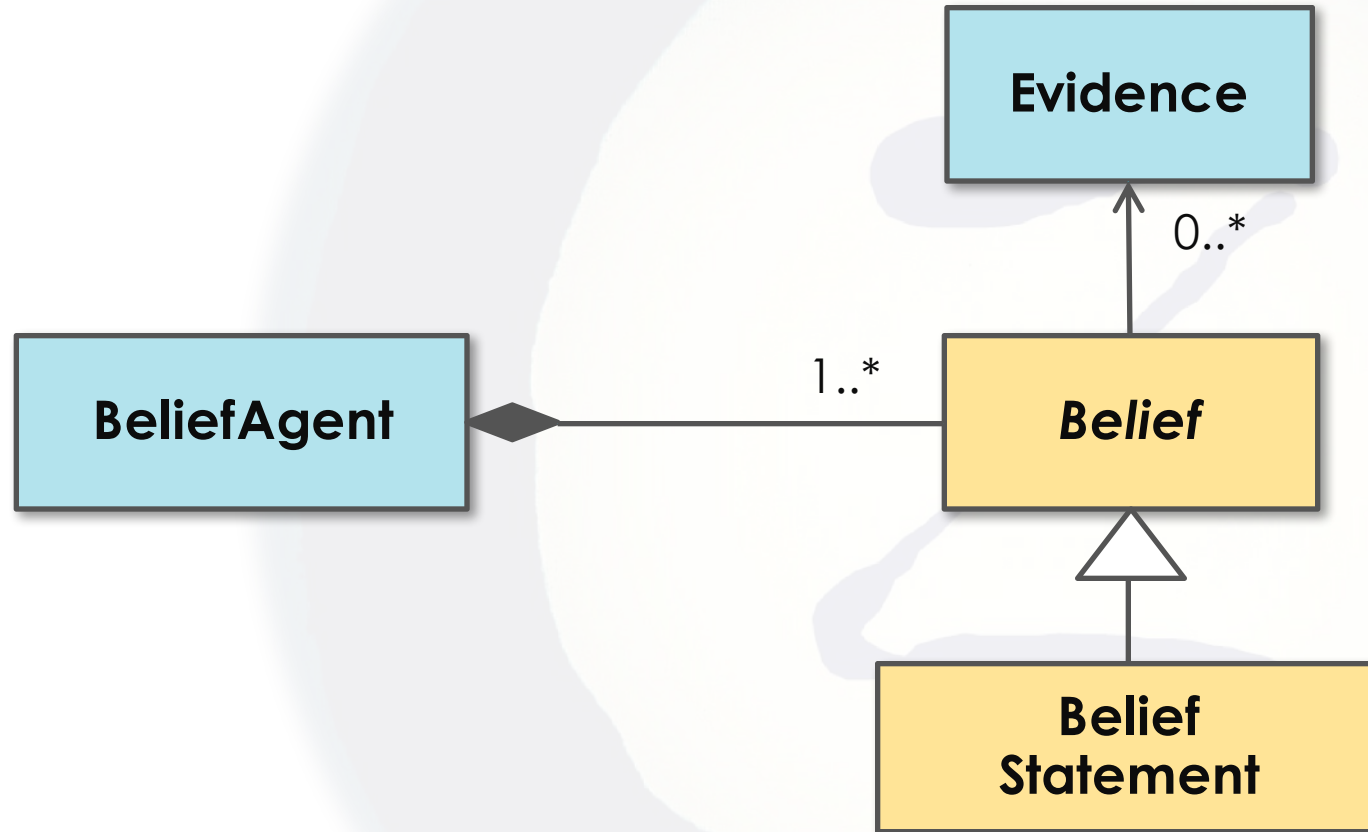


Blind men and an elephant
盲人摸象

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

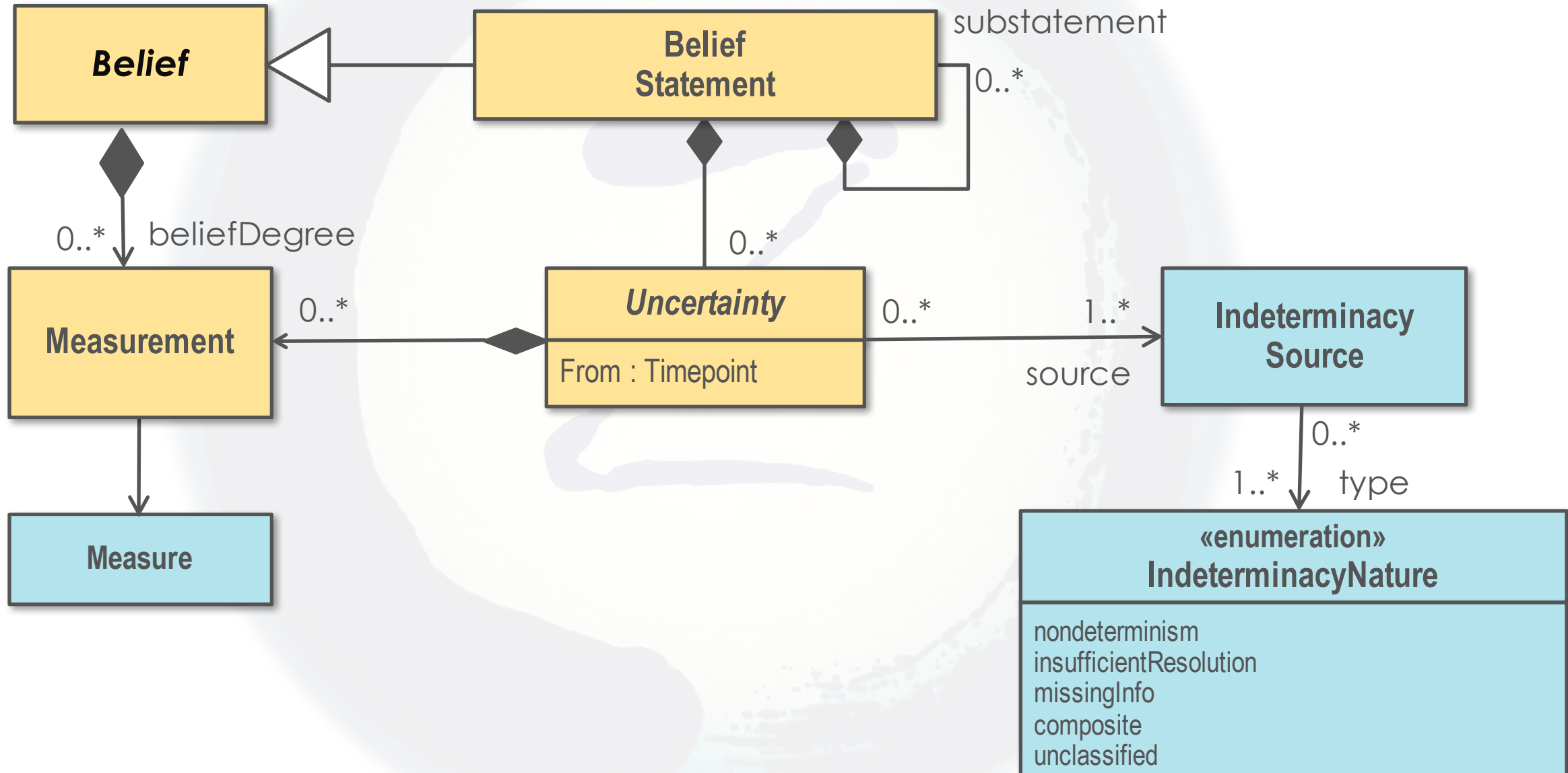


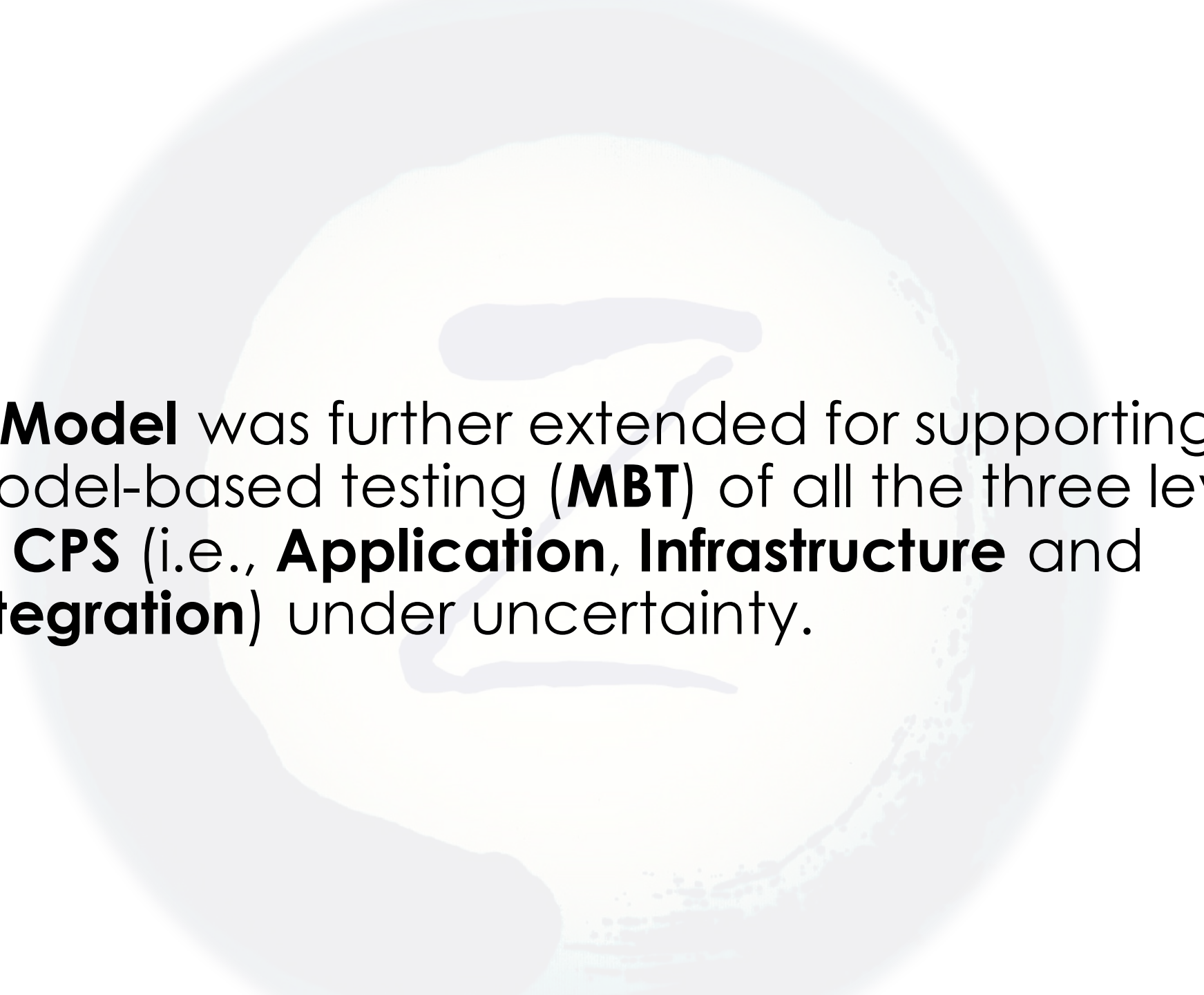
Belief model – Belief



 = objective concept
 = subjective concept

Belief model– Uncertainty



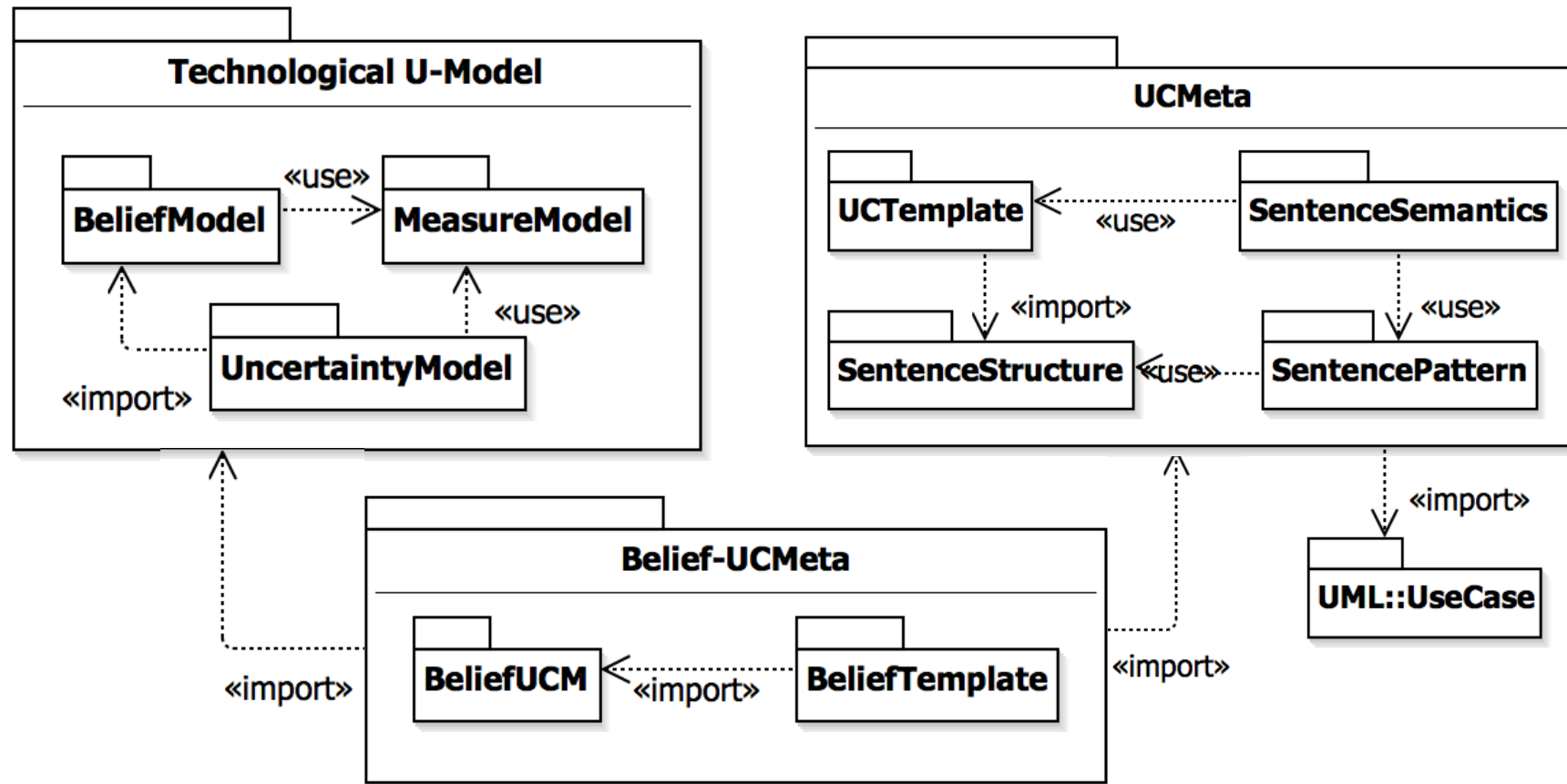


U-Model was further extended for supporting model-based testing (**MBT**) of all the three levels of **CPS** (i.e., **Application**, **Infrastructure** and **Integration**) under uncertainty.



U-RUCM: Specifying uncertainty requirements as use case models

U-RUCM integrates U-Model and RUCM.



U-RUCM is a working methodology.

- Video for demonstrating U-RUCM
 - ✓ http://zen-tools.com/rucm/U_RUCM.html
- Technical Report
 - ✓ <https://www.simula.no/publications/specifying-uncertainty-use-case-models-industrial-settings>

Specifying Uncertainty in Use Case Models in Industrial Settings

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Specify uncertainty with U-RUCM in industry settings

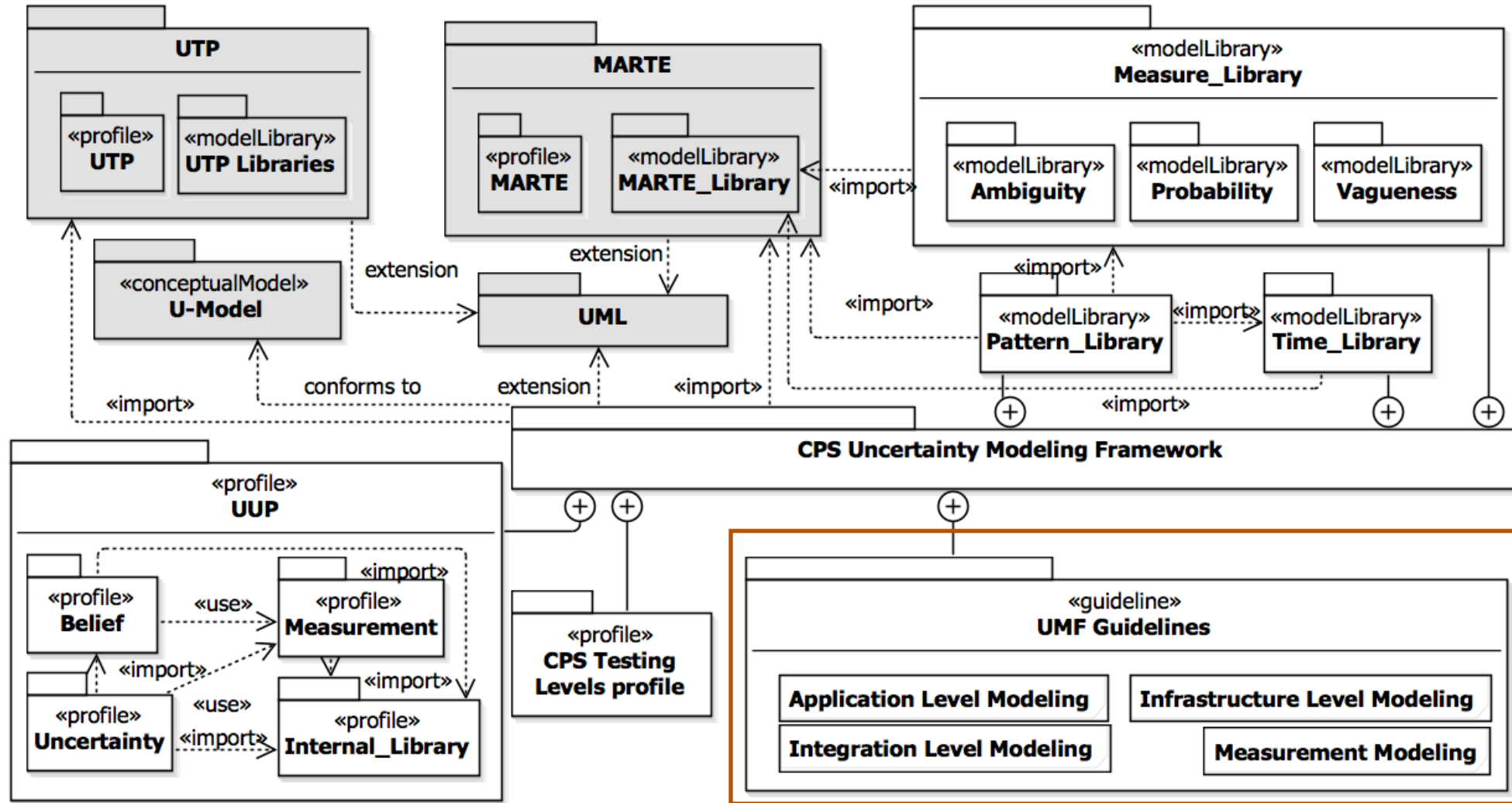


- U-RUCM was able to **significantly improve on characterization, and understanding of uncertainty** requirements.
- Key experience
 - ✓ Learn about uncertainty by applying U-RUCM
 - ✓ Systematically **discover unknown known indeterminacy sources and uncertainties** and **transforming them into known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

UMF: Uncertainty Modeling Framework

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

UMF is a comprehensive UML-based modeling solution.



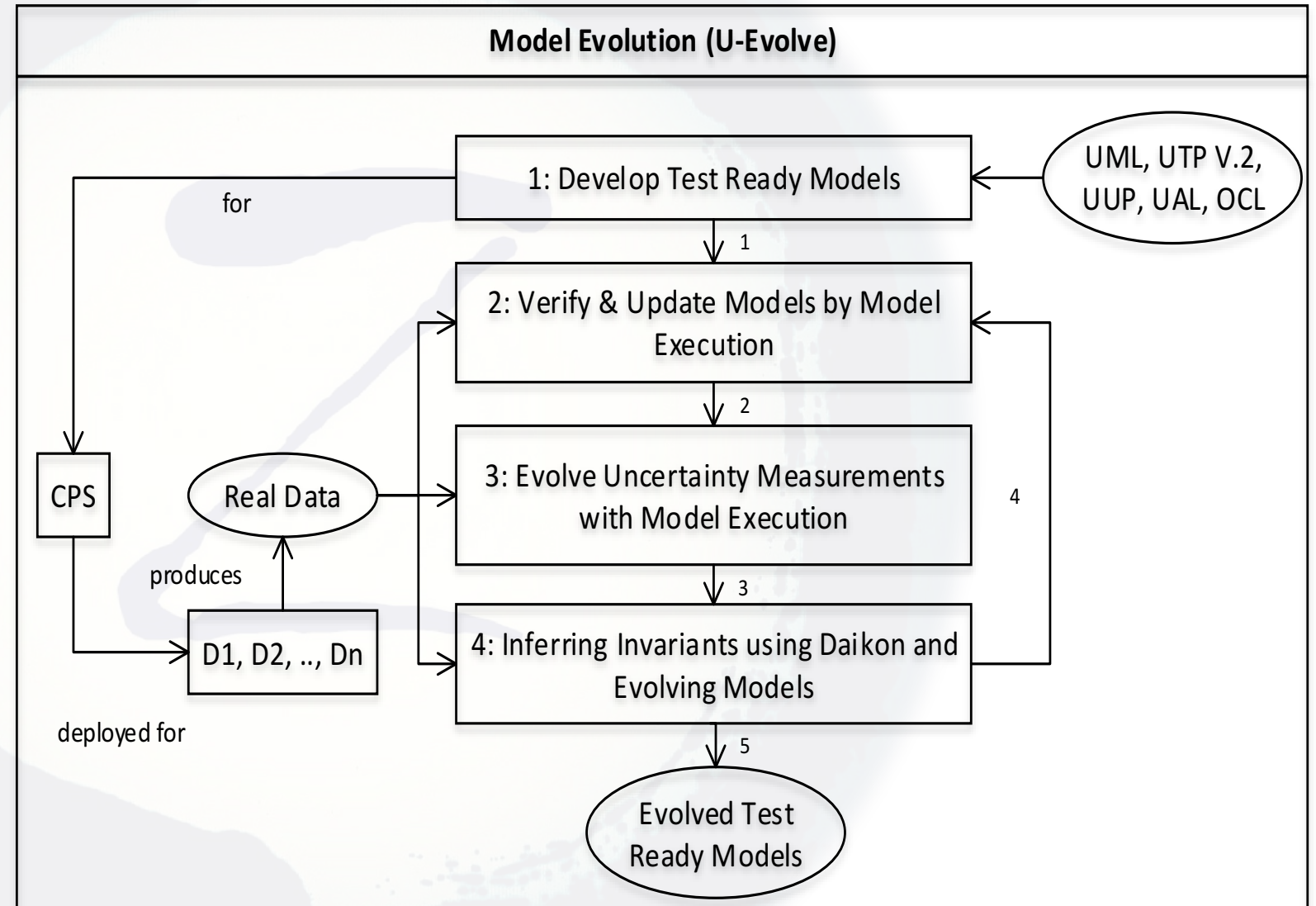
UMF was evaluated with two industrial case studies and one extended open source one!

- 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.

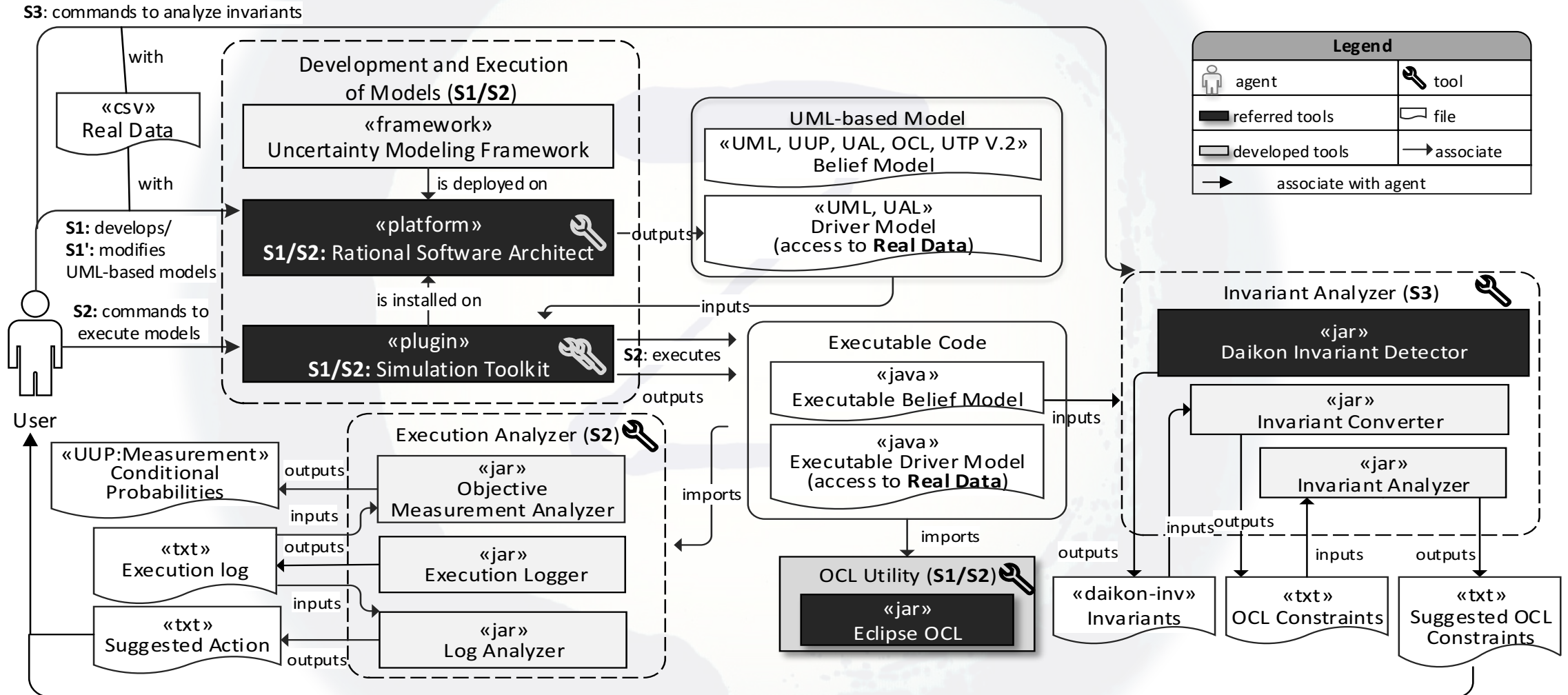


U-Evolve: Evolving UMF Test Ready Models with Uncertainty for Testing CPS

Key steps



U-evolve is an integration of tools. Really software engineering 😊

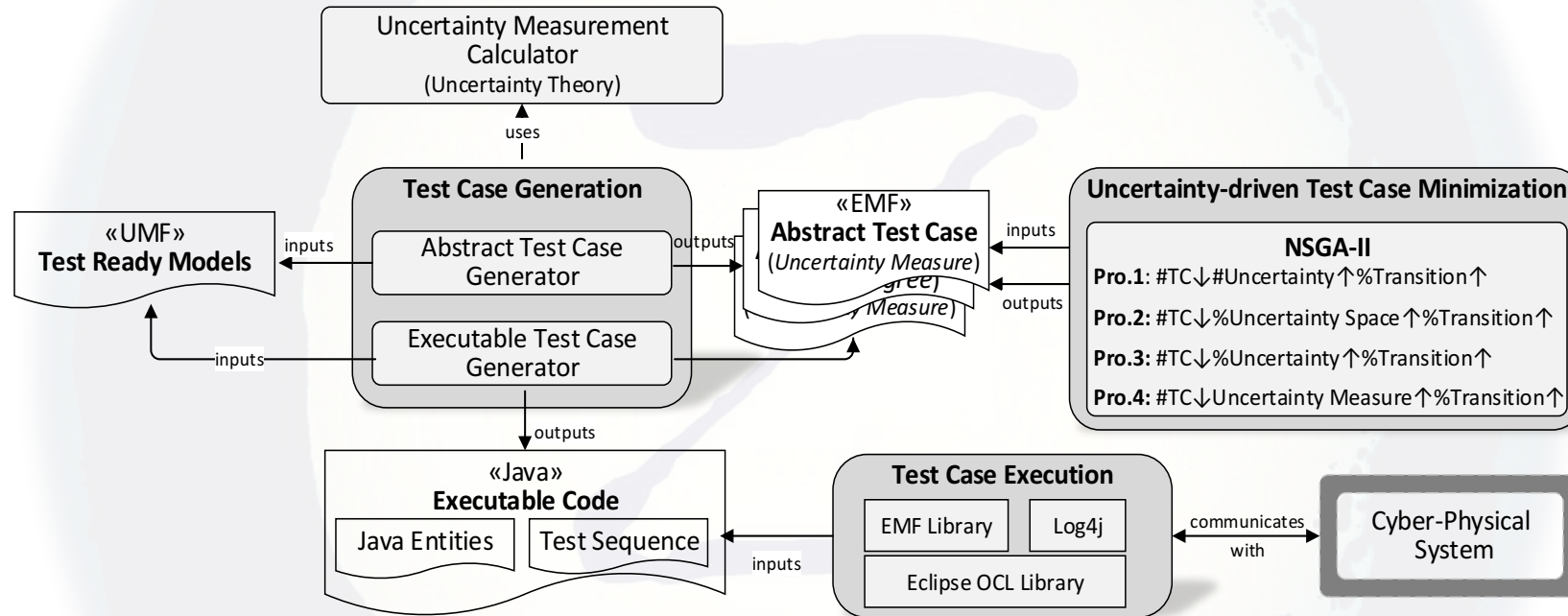


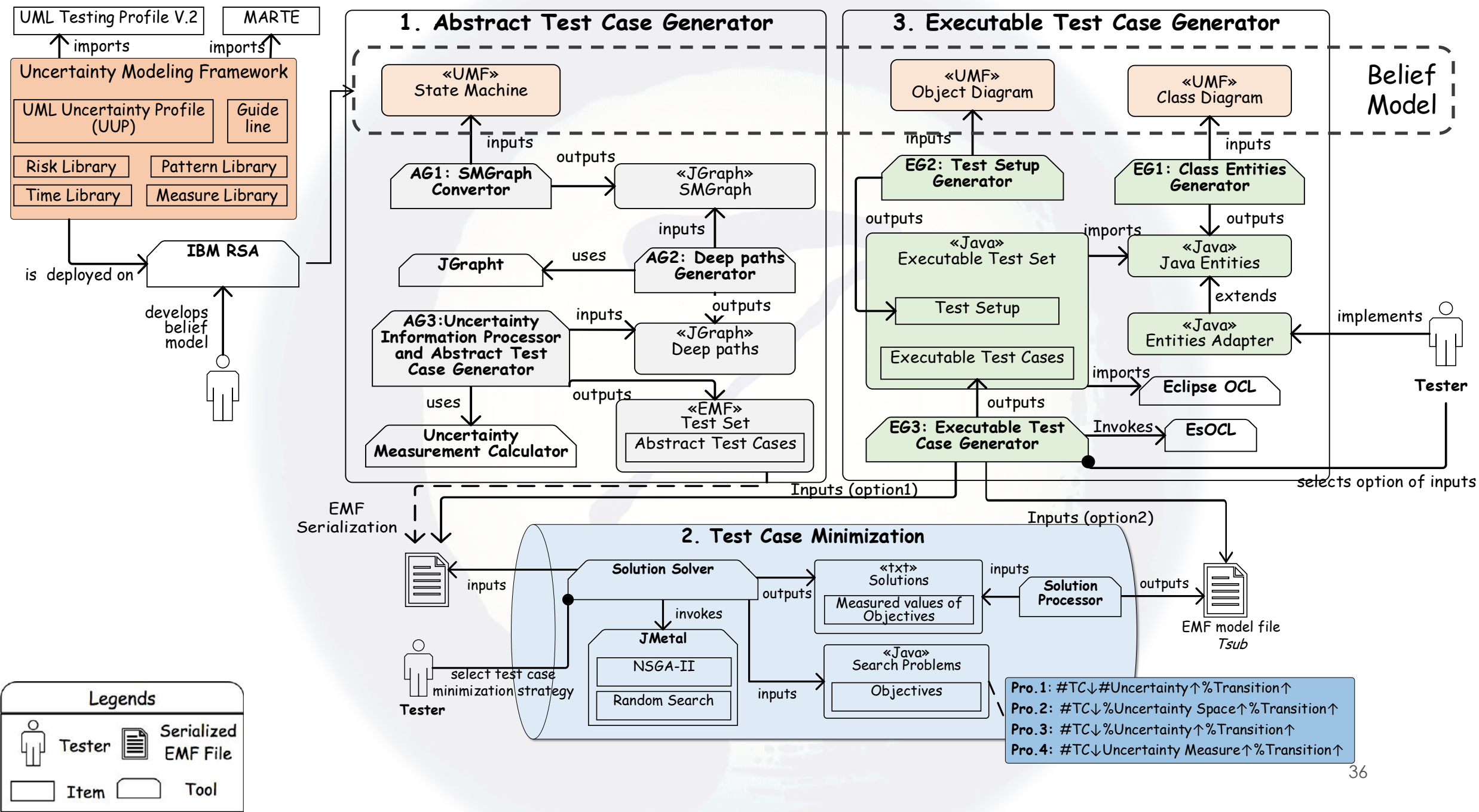
Evaluation

- 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.



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





Integrating MBT, uncertainty theory, and multi-objective search

- Two **test case generation** strategies: All Simple Path and All Paths with a Fixed Maximum Length on Belief State Machines.
- Four **test case minimization** strategies based on **Uncertainty Theory** and **multi-objective search**.
 - ✓ Uncertainty related objectives
 - Max. the number of uncertainties covered.
 - Max. the number of unique uncertainties covered.
 - Max. the overall uncertainty of all the selected test cases.
 - Max. the uncertainty space.
 - ✓ Other objectives
 - Min. the number of test cases.
 - Max. the transition coverage.

Discovered 18 new uncertainties with unknown indeterminacy sources!

- Case studies: SafeHome and Geosports of FPX, Sweden
- Test infrastructures have been built, which enable the **introduction of known indeterminacy sources.**
- **Generated 2085 test cases** with *All Paths with a Fixed Maximum Length*
- **Minimized to 336**, with the best test strategy.
- Observed 98 uncertainties, **18 of which were related to unknown indeterminacy sources.**
- **Obtained results are very promising. We are now systematically conducting empirical studies! Stay tuned 😊**

We demonstrate an industry-strengthening end-to-end MBT solution!

- Research and open source tools
- Commercial Tools
 - ✓ **CertifyIt** for Uncertainty Testing, Easy Global Market (EGM), France
 - **Demo**
- Test execution platforms
 - ✓ Nordic MedTest (NMT), Sweden
 - ✓ ULMA Handling Systems, Spain
 - **Demo**


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-roadmap:requirement_concepts_modeling_core_team
- UML Testing Profile V2
 - ✓ <http://utp.omg.org/>
 - ✓ <http://zen-tools.com/utp/>



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?

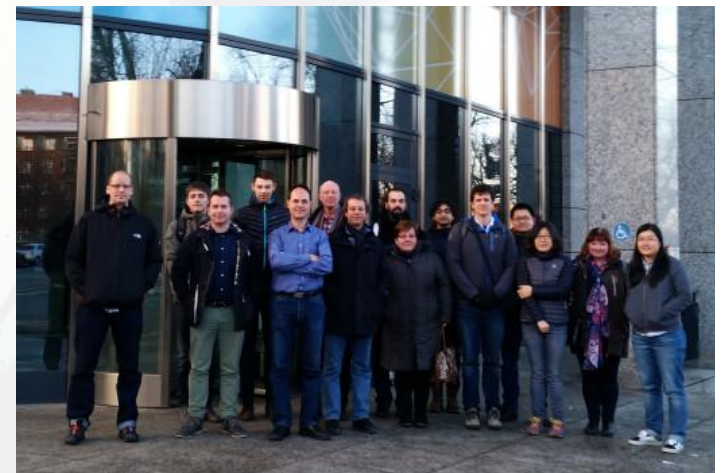


Are we (academia and industry) ready
to embrace and engineer uncertainty?

The only Certainty in Uncertainty is
Uncertainty 😊



ACKNOWLEDGEMENT



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