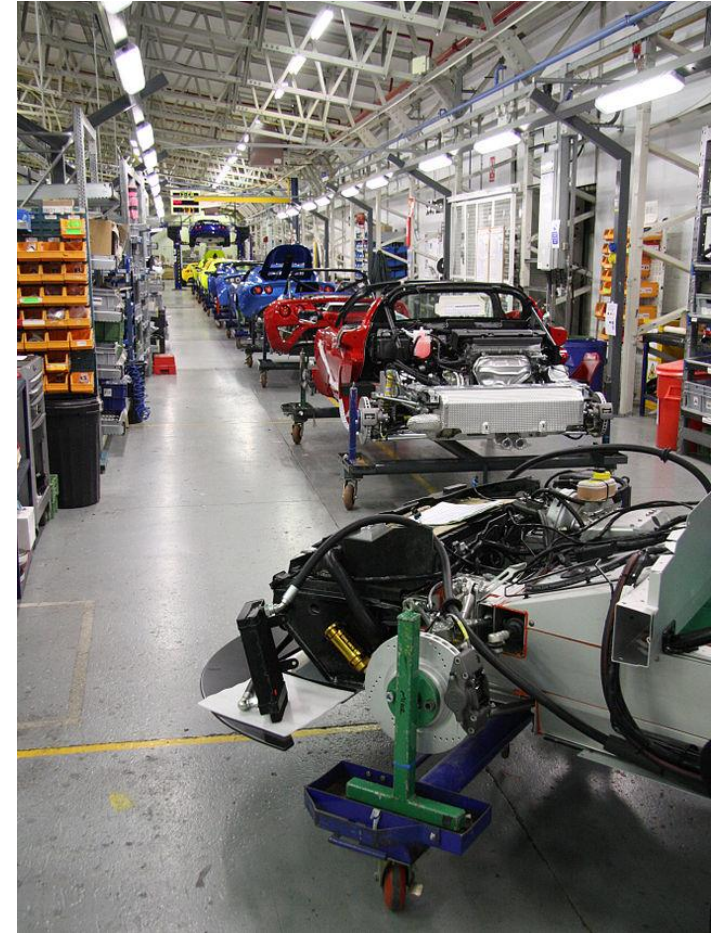


Model-Based Testing Product Lines of Cyber-Physical Systems

Mohammad Mousavi
Halmstad University

Product Lines

- Common core
- Variability points
 - Various models of variability
 - Huge challenges in analysis



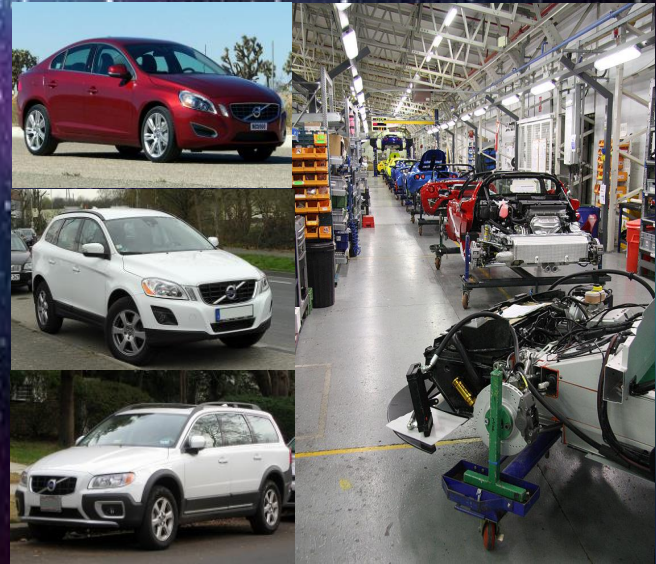
Cyber-Physical Systems

- Communication
(often: asynchronous)
- Computation
(often: distributed)
- Interaction with the
physical world
(incl. sensors, actuators,
human beings)



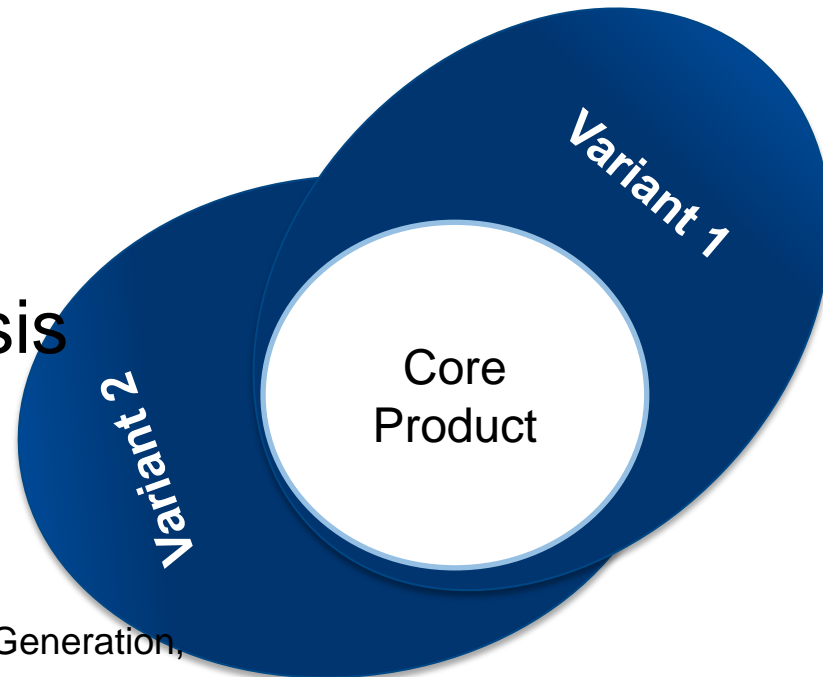
Product Lines of Cyber-Physical Systems

We cannot cover the universe,
Instead, we take samples.



Product Lines: Incremental

- Neat structure
- Limited variability
- Reasonable analysis possibilities



[Simao and Petrenko,
Fault Coverage-Driven Incremental Test Generation,
The Computer J., 2010]

[Kästner, Apel, Kuhlemann.
Granularity in Software Product Lines, ICSE 2008]

Product Lines: Annotational

- Less clear structure
- More expressive: (space and time variability)
- Difficulties with analyzing deletion and modifications

```
delta dStore {
  adds {
}

delta dSingleStore {
  modifies store.Store {
}

delta dMultiStore {
  modifies store.Store {
}

delta dAccessControl {
  modifies store.Store {
    adds private boolean sealed = false;
    modifies read() {
      if(!sealed) {
        return original();
      }
    }
    modifies readAll() {
      if(!sealed)
        return original();
    }
    modifies set(Object value) {
      if(!sealed)
        original();
    }
  }
}
```

[Varshosaz, Beohar, MRM, Delta-Oriented FSM-Based Testing, ICFEM 2015]

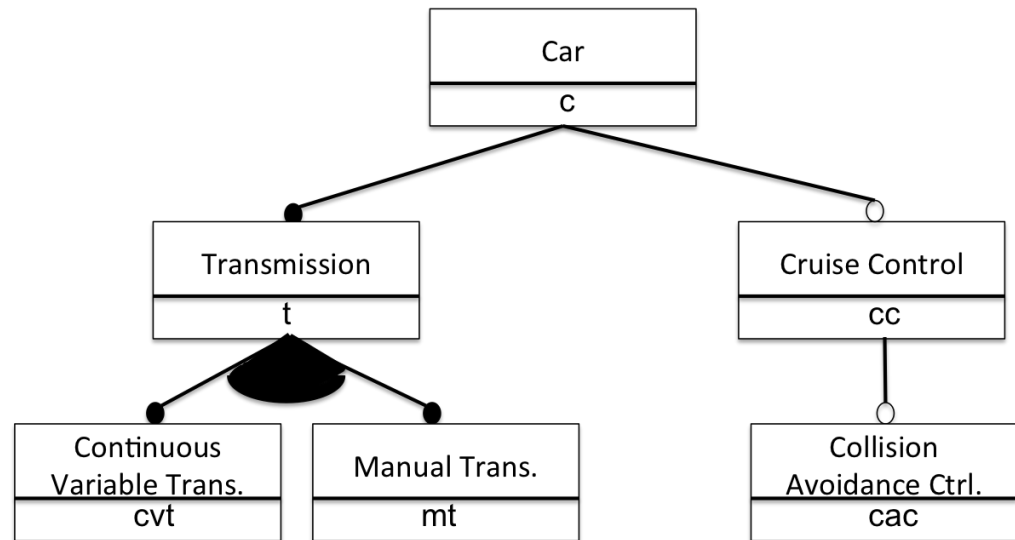
[Schaefer et al. Delta-Oriented Prog., SPLS 2010]

[Apel et al. Strategies for product-line verification:

Case studies and experiments]

Product Lines: Compositional

- Clear structure
- Very expressive
- Difficult to implement and analyze

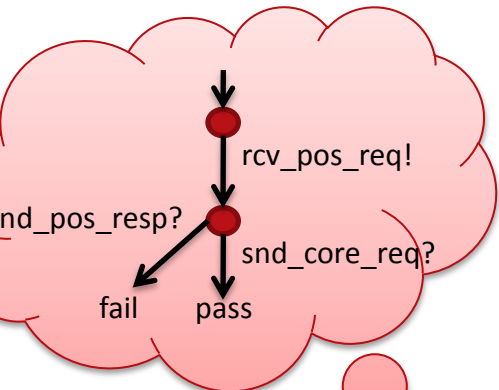


[Beohar and MRM, Spinal Test-Suited for Software Product Lines, MBT 2014]

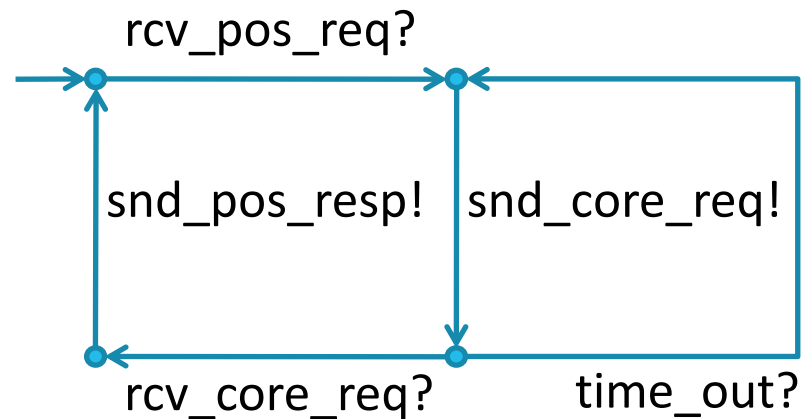
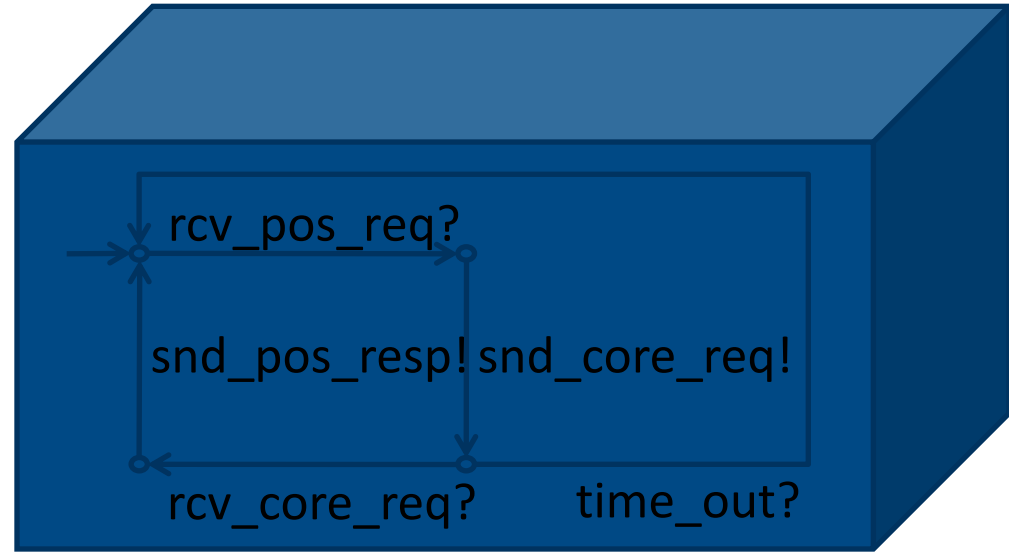
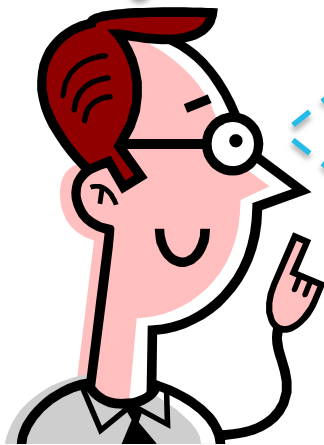
Model-Based Testing

- **Abstractions** from reality
- Separating different **concerns**
- Approximating system **behavior** and / or its **environment**
 - Restricting environment interactions
 - Simpler than actual system
 - Easier to verify

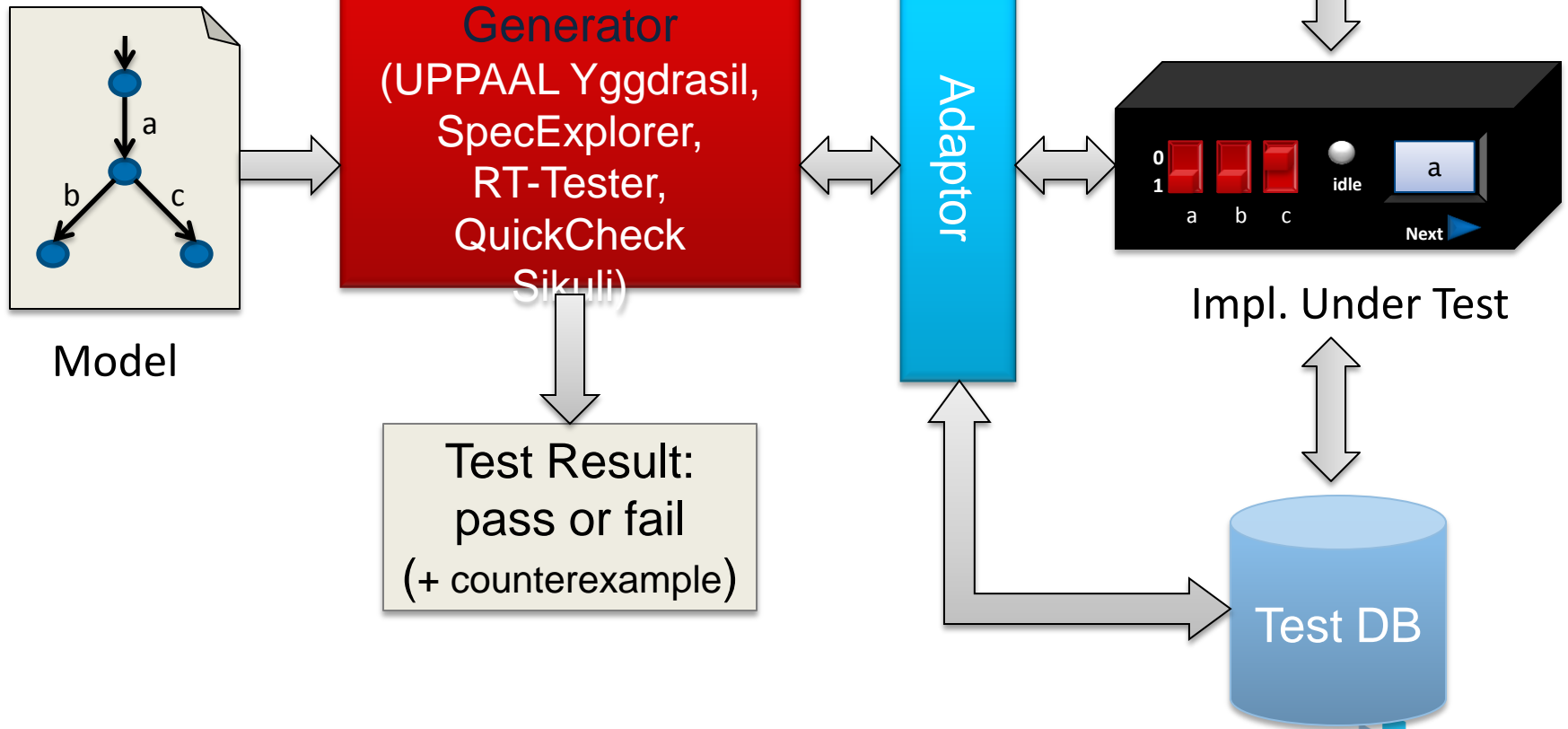
Model-Based Testing



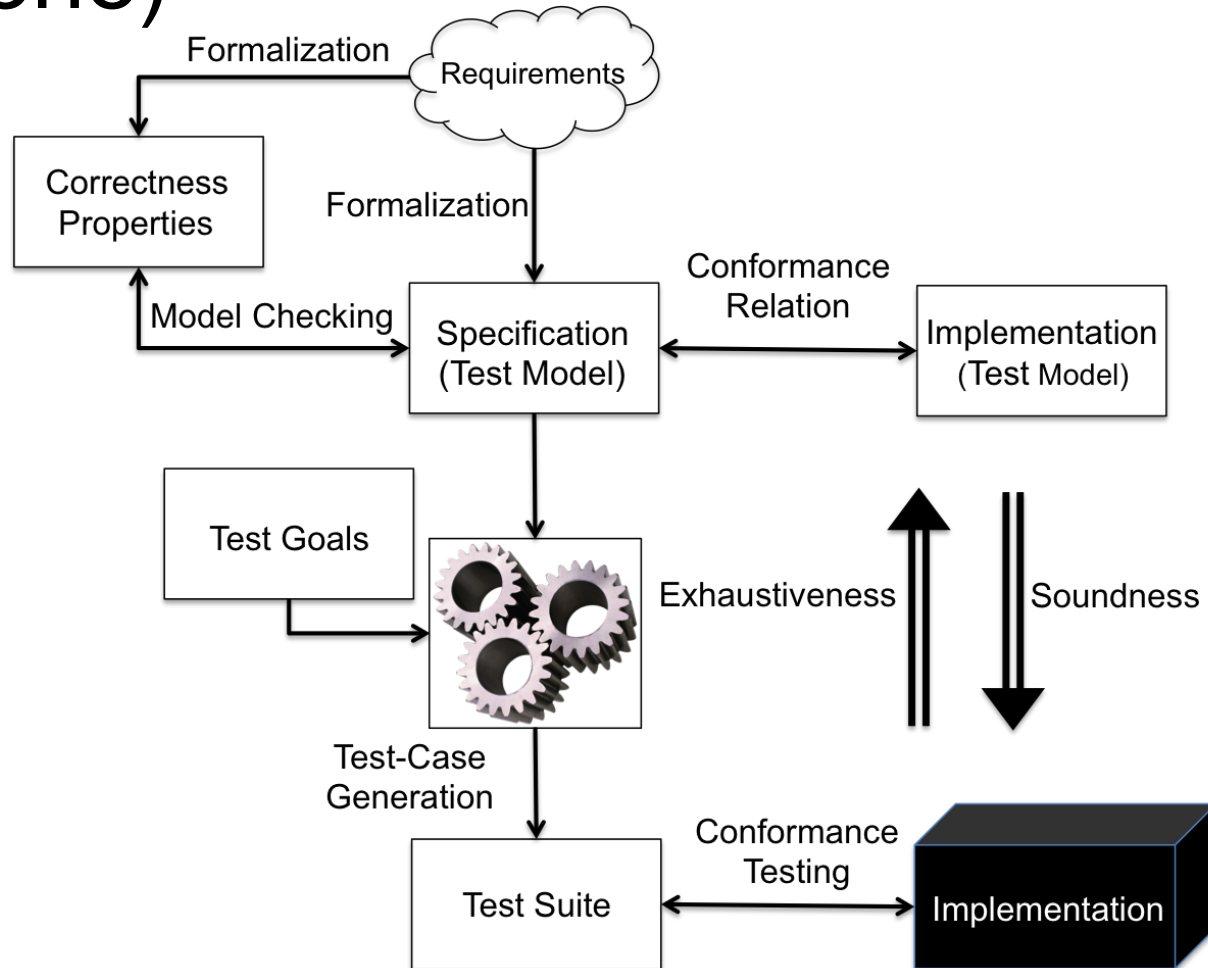
Test Case



Testing Ecosystem



Model-Based Testing (Behind the Scene)



MBT for Product-Lines: Product-Based

- Build a few representative products and test them
- Common practice in industry
- No clue about / hope for coverage

Very Unreliable for Cyber-Physical System:
Taking an autonomous vehicle can take ages...

MBT for Product-Lines: Feature-Based

- Take features and cover them (e.g., individually, pairwise, or T-wise)
 - Very difficult to analyze individual features (complex feature interactions)

MBT for Product-Lines: Family-Based

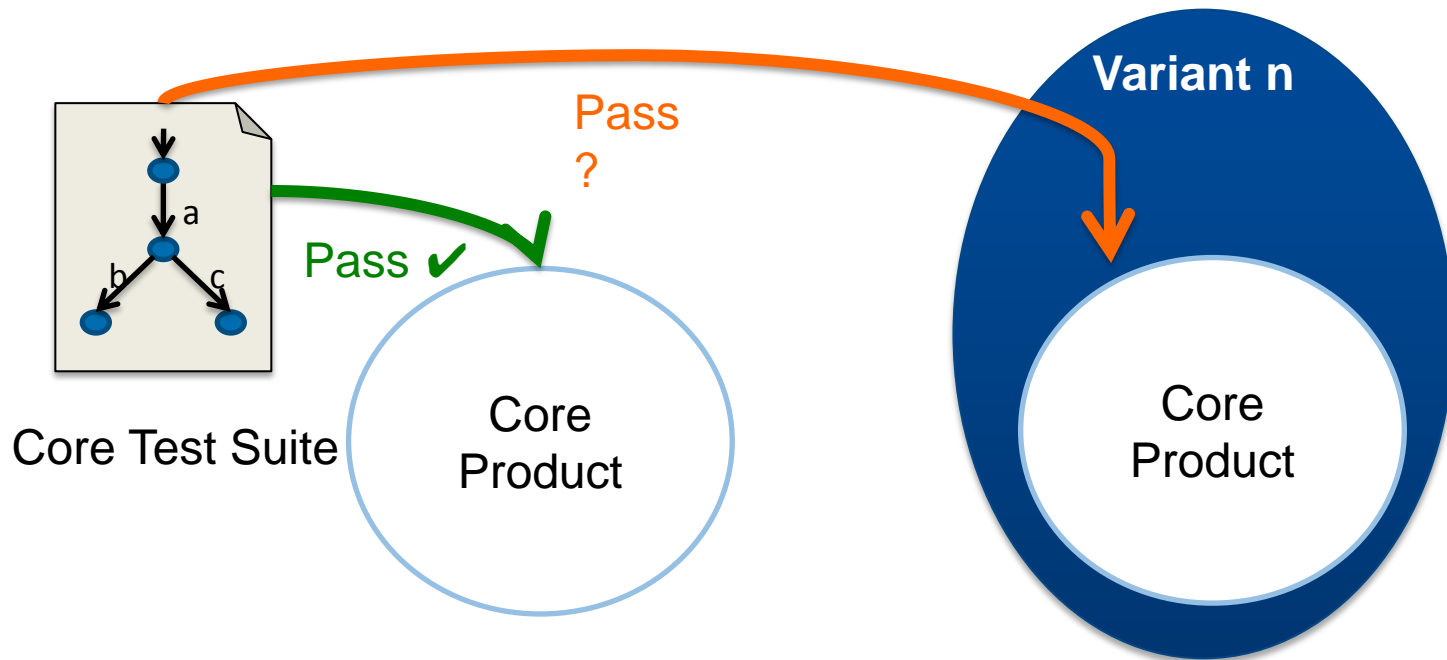
- Use the structure of family to steer test execution
 - Extrapolation problem: Are test results from product 1 also valid for a large set of products?
 - Test-generation modularisation: How to test the difference between product 1 and product 2?

[Dingovskii, Brabrand, and Wasowski, Variability Abstractions. ECOOP 2015]

Difficult problems to solve...

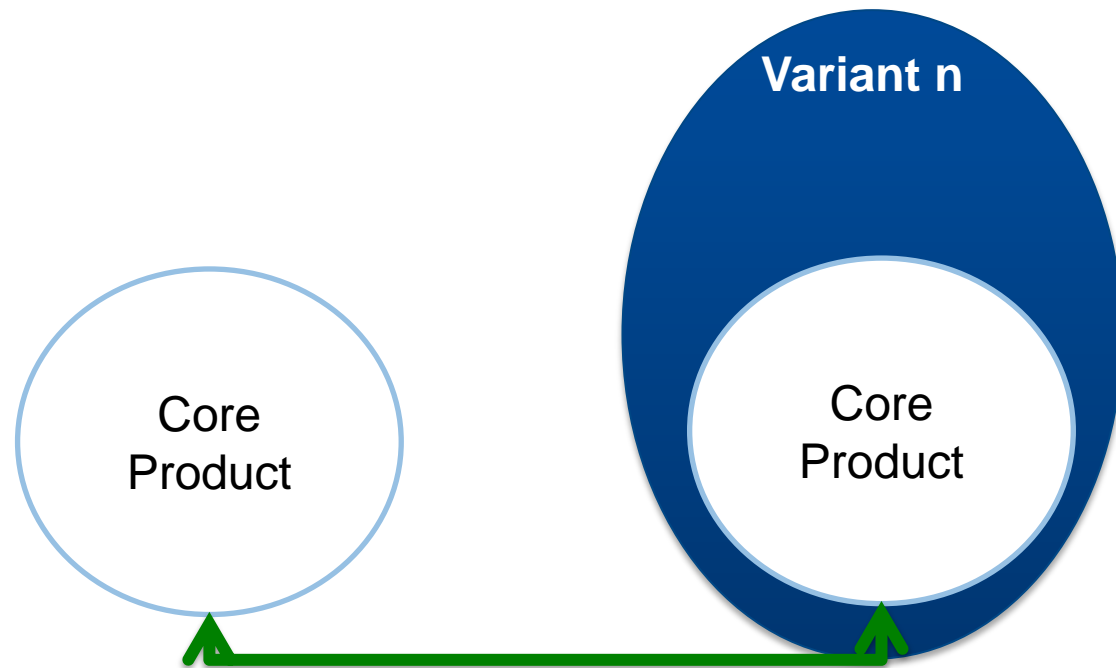
MBT for Product-Lines: Family-Based

Extrapolation problem:



MBT for Product-Lines: Family-Based

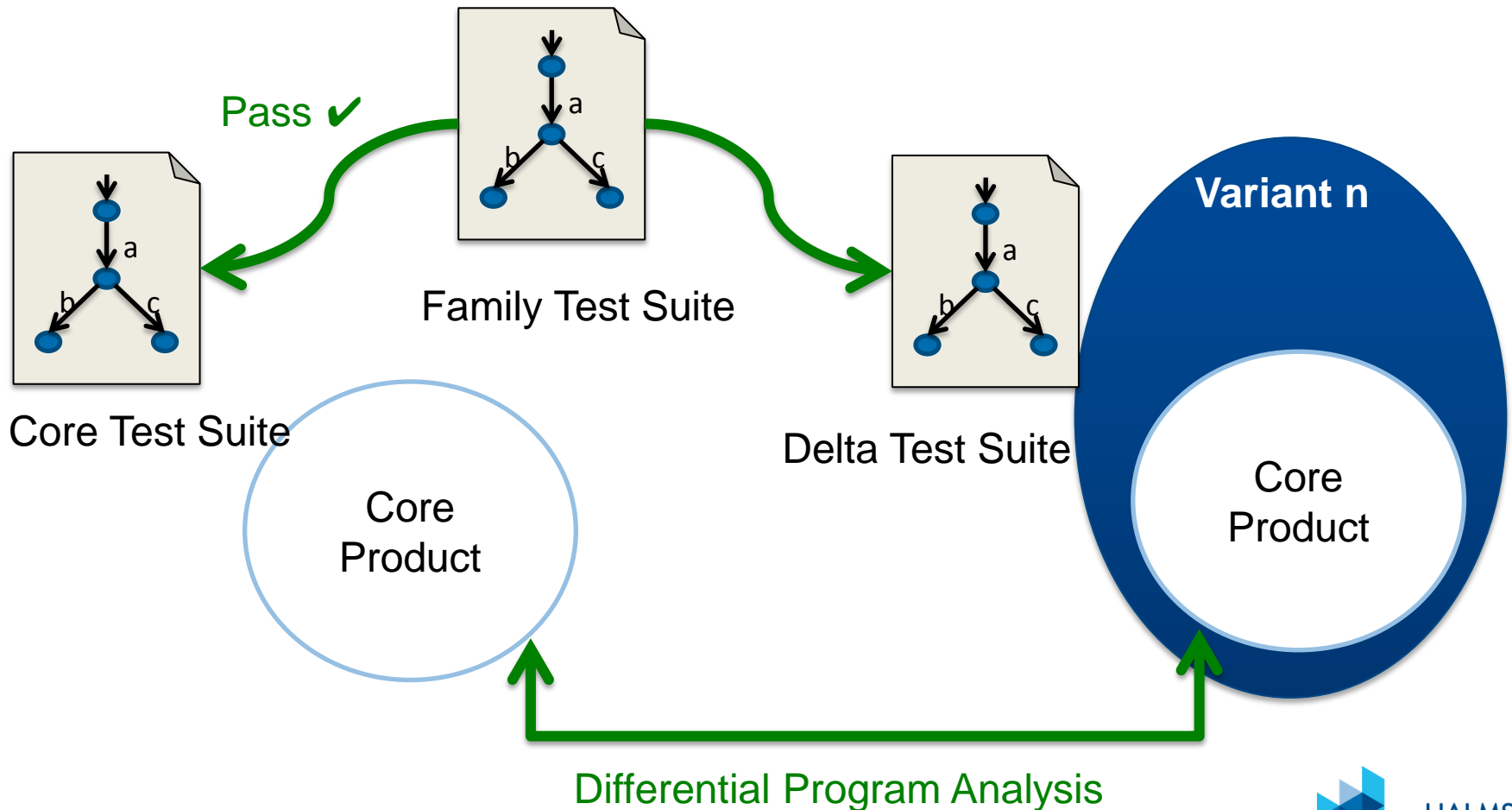
Extrapolation problem: Proposed approach



Differential Program Analysis

[Lahiri et al. Automated Differential Program Verification for Approximate Computing]

MBT for Product-Lines: Family-Based Test-Suite Modularisation:

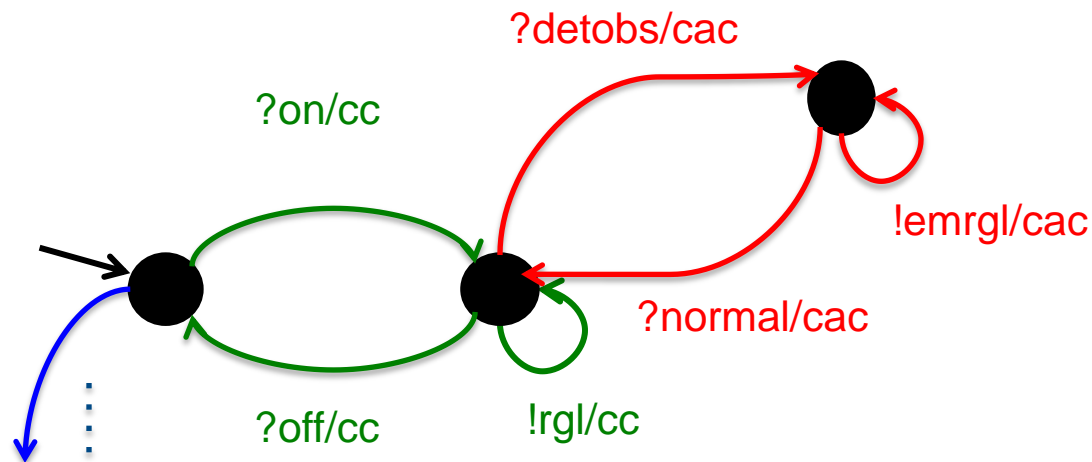


Model and Projection

Features = {c, cc, cac, ...}

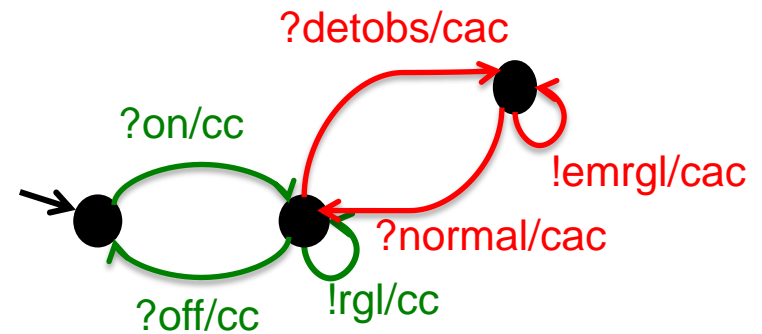
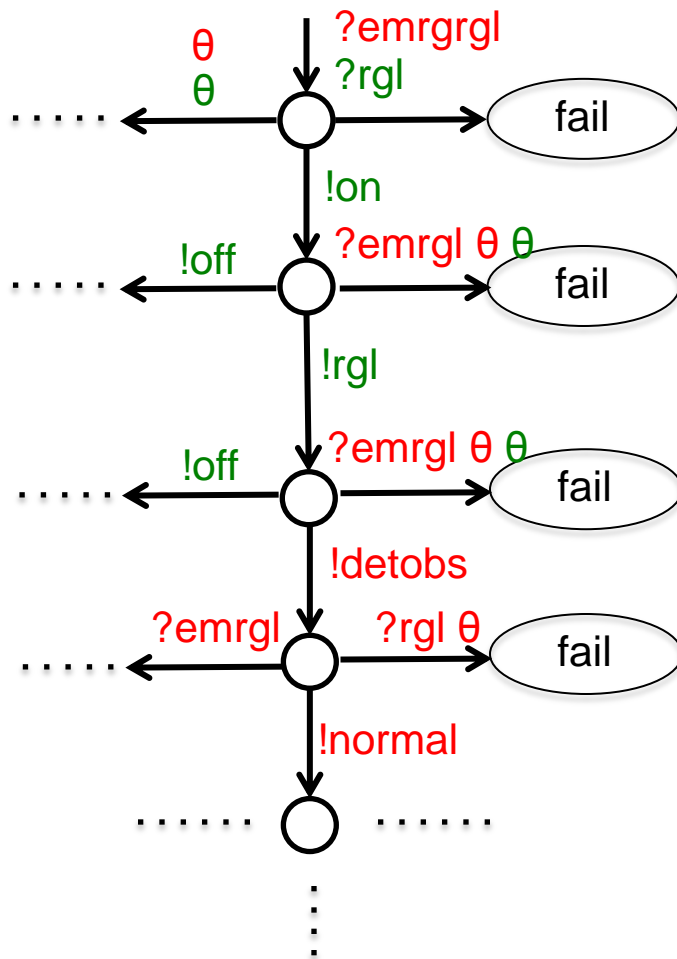
Valid product {c, cc, ...}

Valid product {c, cc, cac, ...}

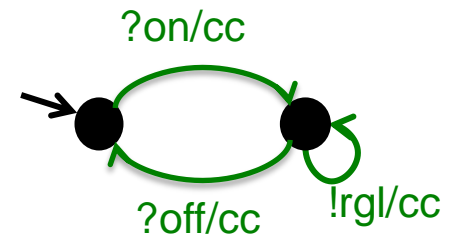
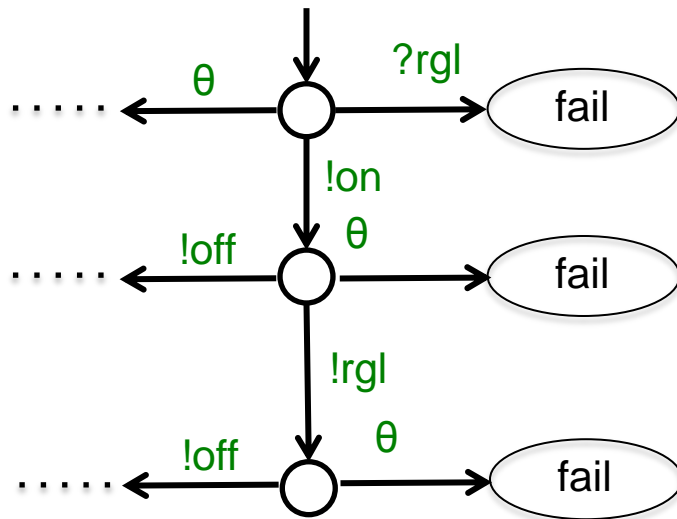


For a more serious model of cruise control, see:
M.A. de Langen, Vehicle Function Correctness, Masters Thesis, TU/e, 2012.

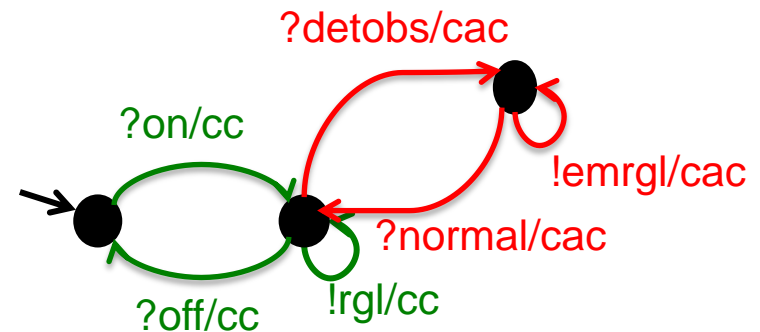
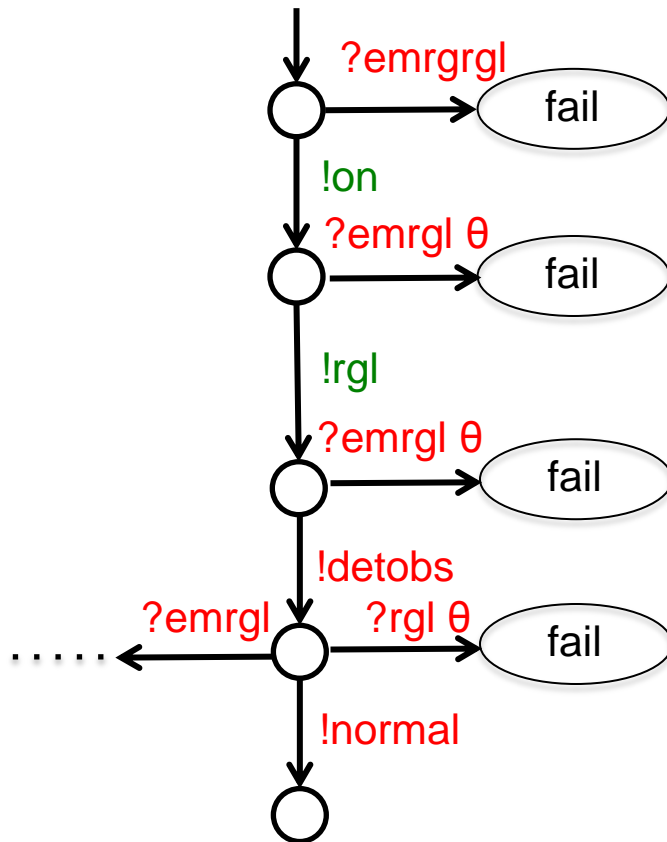
Test Suite



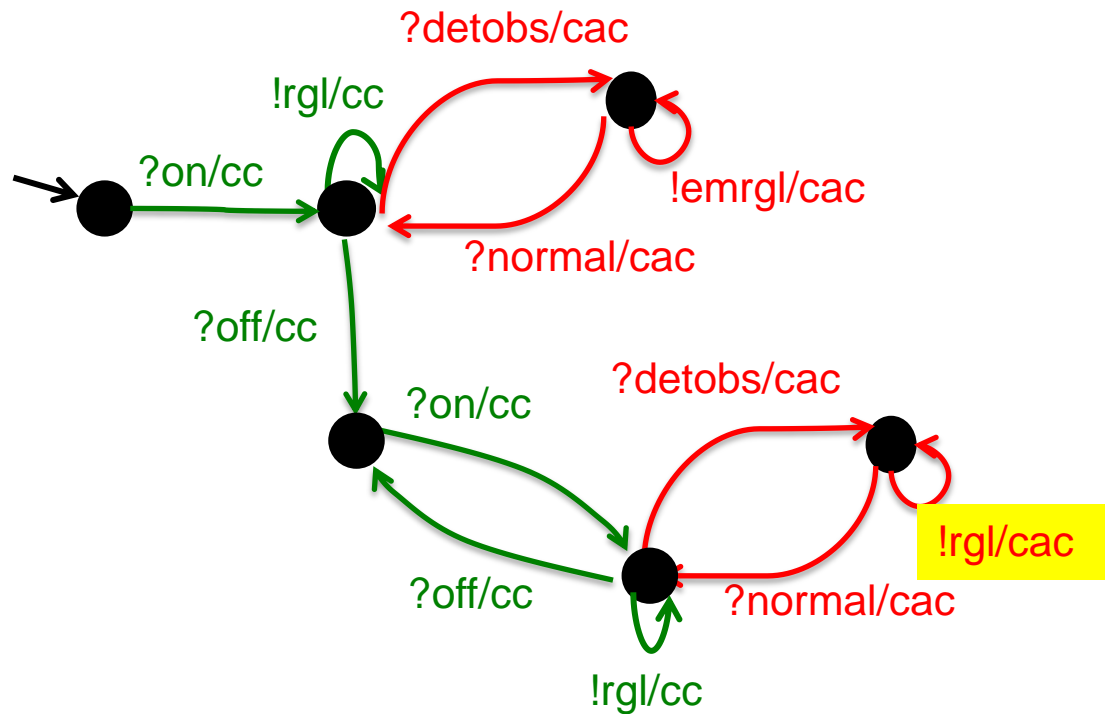
Test Suites: Projection



Test Suites: Residual Testing



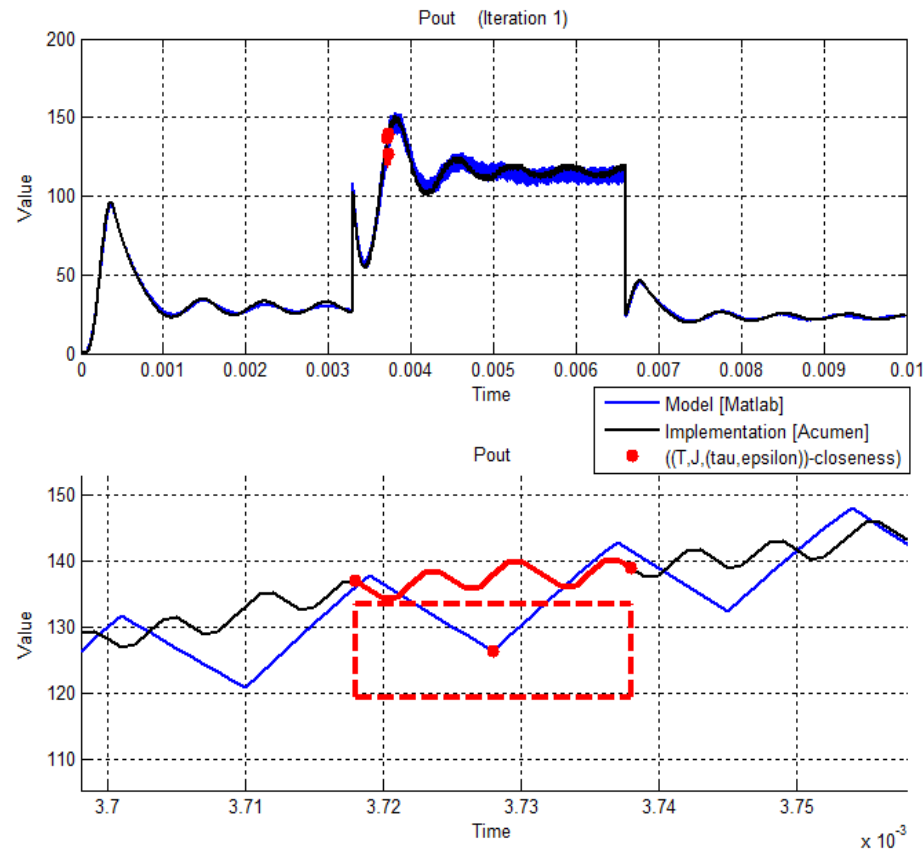
Feature Interaction



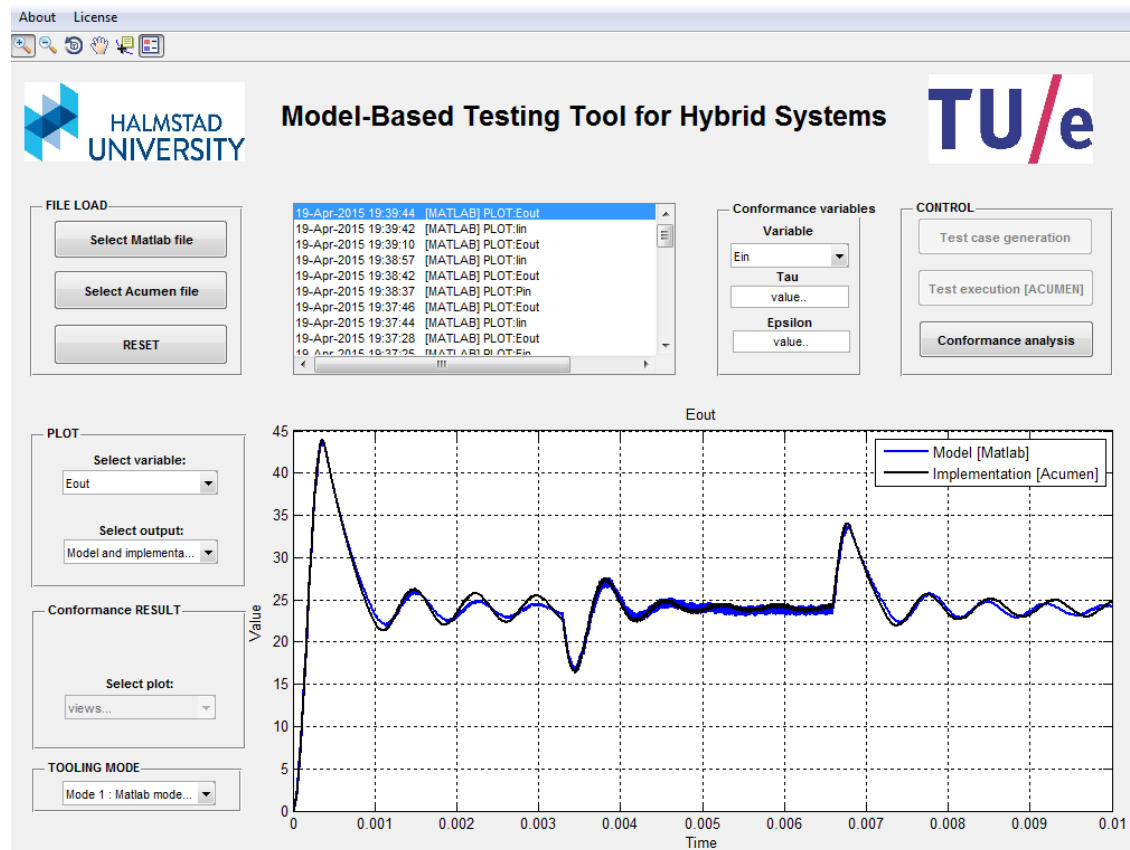
MBT for Cyber-Physical Systems

Challenges:

- Modeling system dynamics (differential equations, accuracy of numerics)
- Sampling inputs and outputs, approximate conformance (in time and value)
- Coverage



MBT for Cyber-Physical Systems



[Aerts, Reniers, MRM.
Tool Prototype for Model-Based Testing of
Cyber-Physical Systems, ICTAC 2015]

AUTO-CAAS: Automated Consequence Analysis for Automotive Software

- Focus: Automotive Open System Architecture
- **Goal: Trace concrete failures of automotive software to deviations from AUTOSAR standard**
- **Means:**
 - **Model-Based Testing** technology from **Halmstad University**
 - **Formalization** of AUTOSAR protocol stacks from **QuviQ** and open source **implementation** of AUTOSAR from **ArcCore**
- 3 years project (2015-2018),

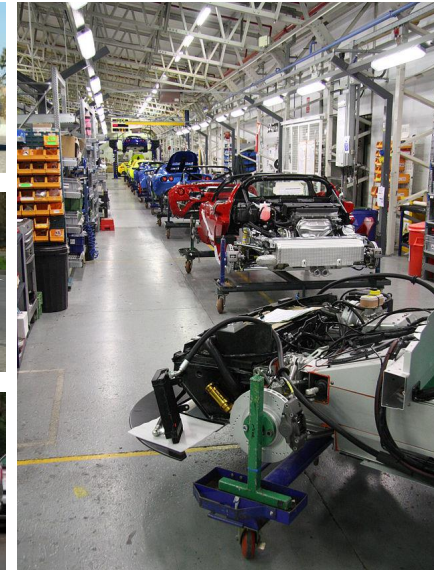


MBT4SPL: Model-Based Testing for Software Product Lines

- Goal: Efficient Testing of Software Product Lines

“Testing a product line should take far less effort than testing each and every individual product.”

“To test a product line efficiently and effectively, we find few representative products that provide maximal feature covering.”



- Means: Model-Based Testing (based on state machine specifications)
- Application areas: healthcare and automotive software
- 6 years project (2013-2019)

EFFEMBAC: Efficient Model-Based Testing of Concurrent Software

- Goal: **Compositional testing of concurrent software**

“Integrating symbolic execution with model-based testing”

“Building data-rich test models by combining requirements and gray-box structural information”

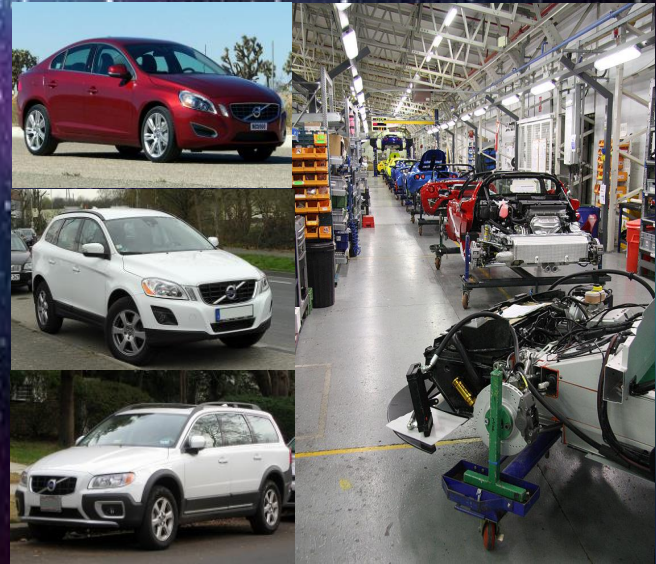
- 5 years project (2015-2019),
- Funded by the Swedish Research Council (VR)



Vetenskapsrådet

Product Lines of Cyber-Physical Systems

We cannot cover the universe,
Instead, we take samples.



6th Halmstad Summer School on Testing

http://cores.hh.se/TEST_2016



Dino Distefano
FaceBook and
Queen Mary U.



Alastair Donaldson
Imperial College



Jeff Offutt
George Mason U.



Marielle Stoelinga
U. Twente



Alexandre Petrenko
Comp. Sys. Research Inst.



Per Runesson
Lund U.

Thank You!

Mohammad Mousavi
m.r.mousavi@hh.se