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# Towards Fault-based Generation of Test Cases for Dependable Embedded Software

4. Workshop Entwicklung zuverlässiger Software-Systeme
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Tut es, was es soll?

Immer?

Tut es nicht, was es nicht soll?

Nie?

# Integrierter Entwicklungsprozess - *embedded*

# Testen

Zweck:

- Fehlerwirkungen nachweisen
- Qualität bestimmen
- Vertrauen erhöhen

Eigenschaften:

- Benötigt Domänenwissen
- Variabel in den Ergebnissen
- Aufwändig (50-80%)
- Testdurchführung am Echtzeitsysteme mitunter teuer

Wunsch:

- Wenig Testfälle (Testdurchführungsaufwand)
- Genug/ die richtigen Testfälle (Vertrauen)

# Mutation Testing

- Richard Lipton, 1971
- DeMillo/Lipton/Sayward, 1978
- Mutant: Stellvertreter für fehlerhaftes Artefakt
- Bewertung von Test Suiten
- Geringe industrielle Nutzung, rege akademische Nutzung

- Kleine Fehler, große „gehen mit“;
- „Direkteres“ Maß als gängige Abdeckungsmaße – Fehlerbezug
- Parametrisierbar über Fehlermodell
- Fehlermodell sprachabhängig

# Mutation Based Test Case Generation

- Testfall für bestimmte Qualität finden
- Konformanz Beziehung (Refinement)
- Behauptung:
  Mutiertes Artefakt („Implementierung“)
  ist konform zum
  Original-Artefakt („Spec“)
  (für alle Input-Output-Sequenzen)
- Gegenbeispiel = Testfall
- Model checking/Constraint solving
- Nutzbar auf allen „ausführbaren“ Artefakten:
  - Modell
  - Code
  - Executable

# Abdeckung

```
context TriangType(a: int, b: int, c: int): String
pre: a < (b+c)  and  b < (a+c)  and  c < (a+b)
post: if ((a = b) and (b = c))
      then result = "equilateral"
      else if ((a = b) or (a = c) or (b = c))
           then result = "isosceles"
           else result = "scalene"
      endif endif
```

- Testfälle

*a = 1, b = 1, c = 1, result = "equilateral"*
*a = 2, b = 2, c = 1, result = "isosceles"*
*a = 2, b = 3, c = 4, result = "scalene"*

- Erkennen nicht:

```
post: if ((a = a) and (b = c))
      then result = "equilateral"
      else if ((a = b) or (a = c) or (a = c))
           then result = "isosceles"
           else result = "scalene"
      endif endif
```

- Erkennt beides:

*a = 1, b = 2, c = 2, result = "isosceles"*

# Model-based GENeration of Tests for Embedded Systems

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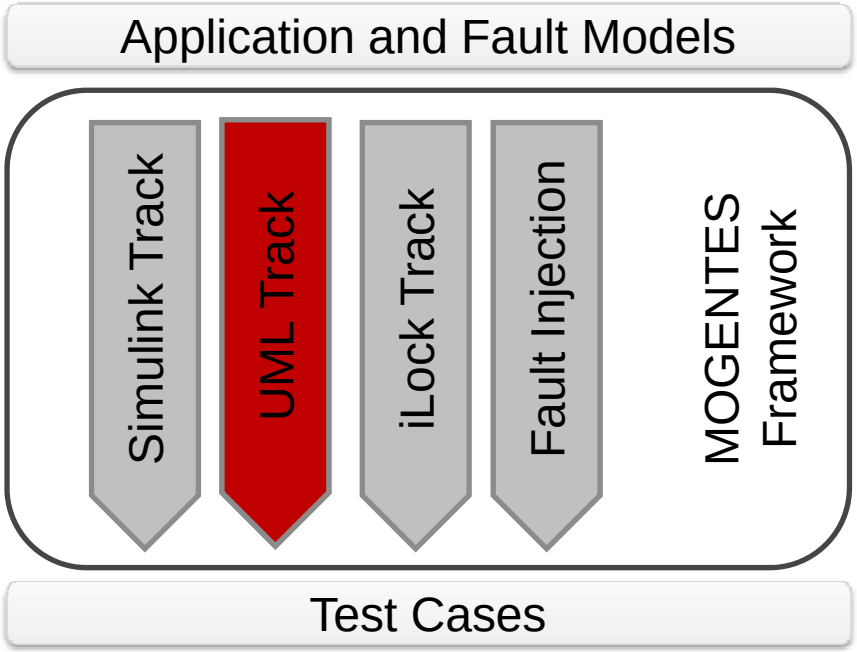
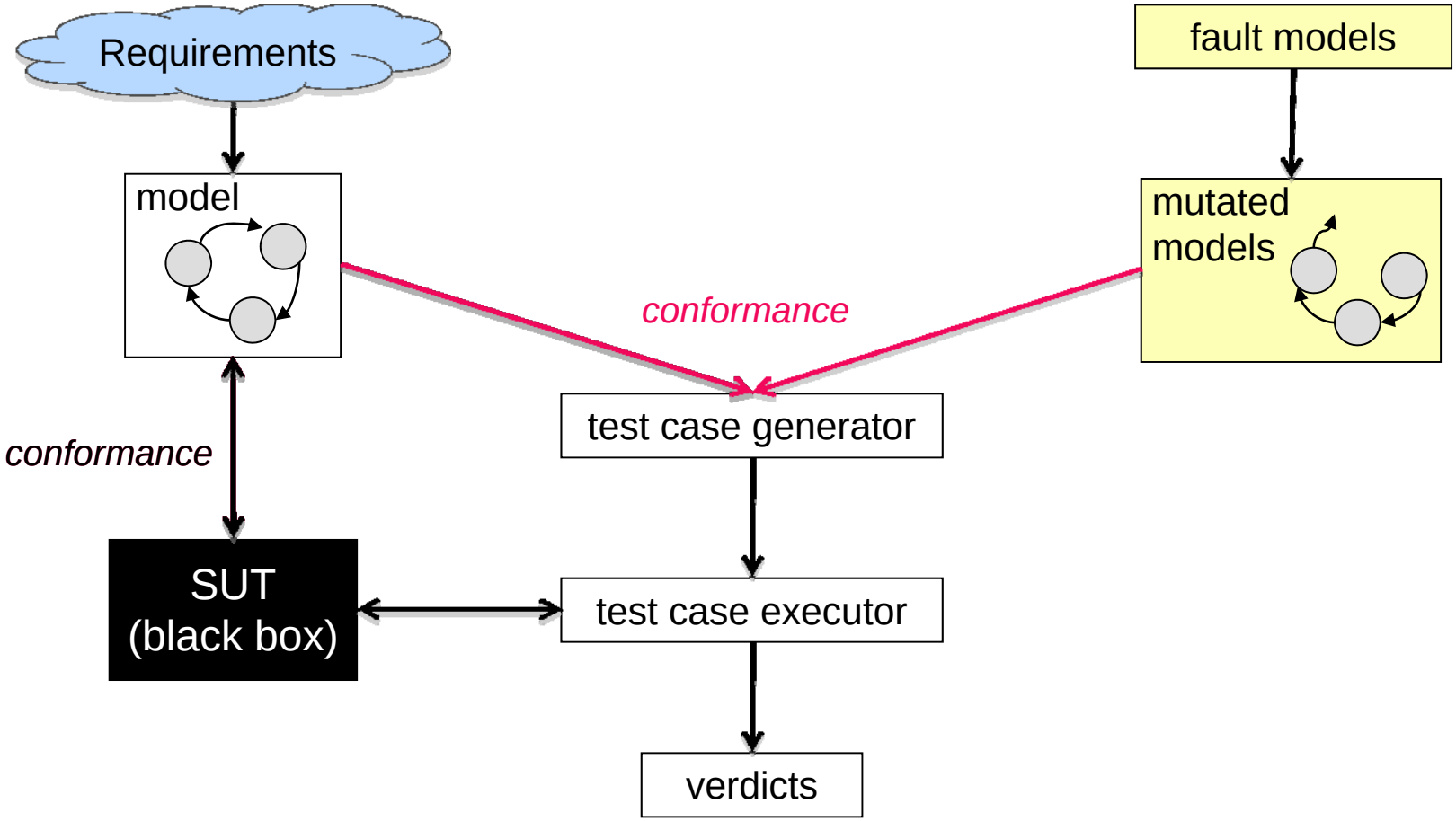
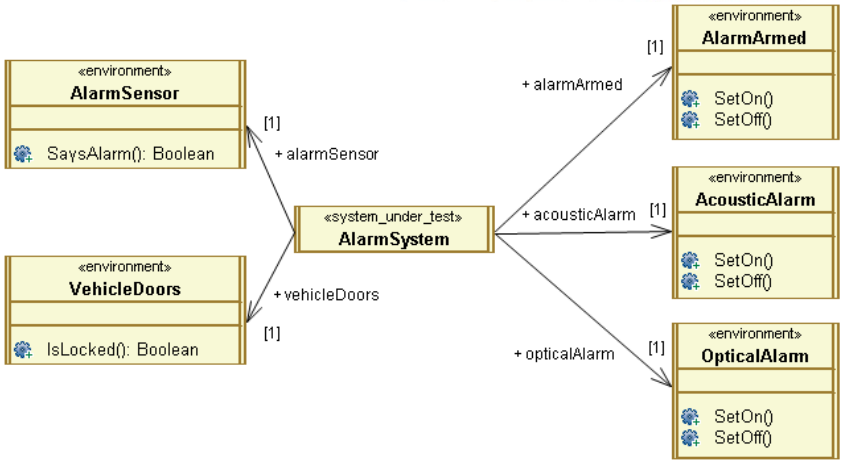


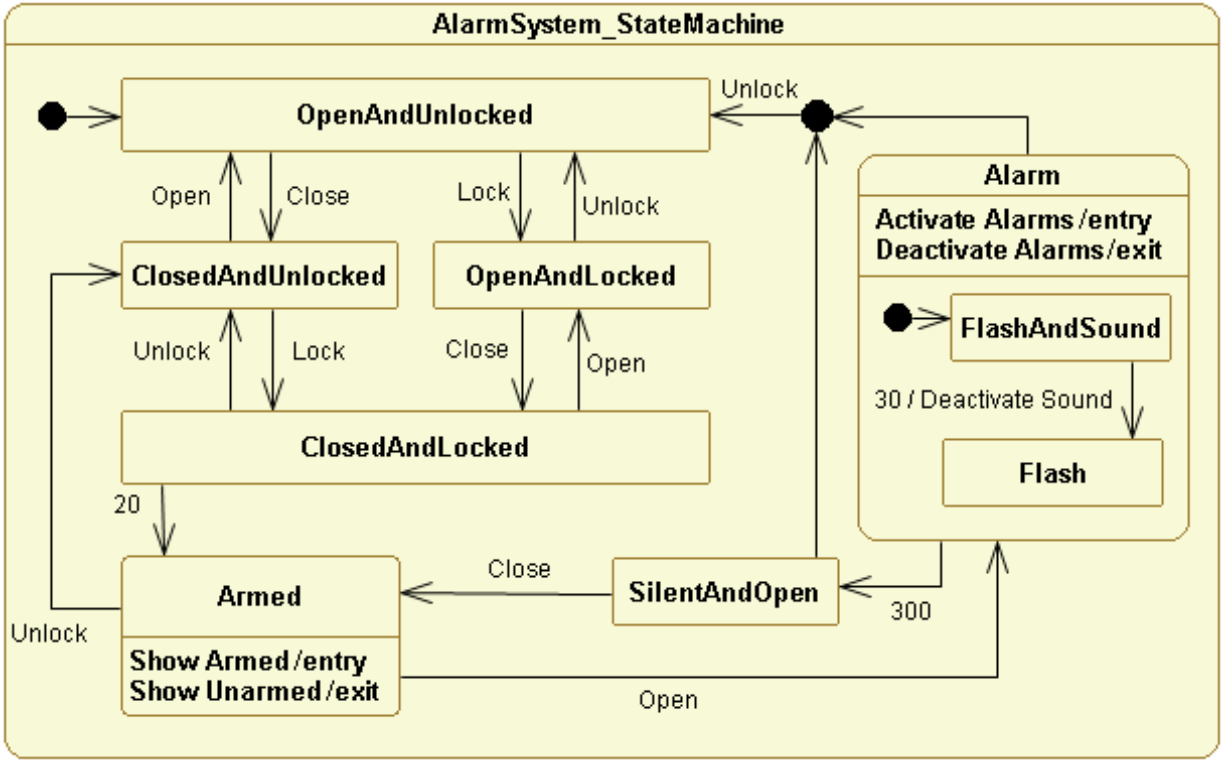

# Model-Based Mutation Testing



# UML Modelle

- Class diagrams (structure)
- State machines (behaviour)
- Stereotypes (testing interface, additional markup)



# Unterstützte UML Elemente

- state machine diagrams
- (active) Classes
- lightweight inheritance
  (no polymorphism / late-binding)
- OCL constraints (guards)
- orthogonal regions
- nested regions
- signals (incl. broadcast)
- time trigger
- substates
- junctions
- change triggers

# Mutationsoperatoren

- Init values, constants, OCL literals, AGSL literals:
  - Constant Value Variation Step / Factor
  - Enum Value Exchange
  - Set Constant Value to Zero/Max
- States:
  - Remove State Entry/Exit Action
  - Exchange State Entry/Exit Action Method
- Transitions:
  - Remove Transition
  - Exchange Transition Source/Target
  - Exchange Transition Trigger
- Triggers
  - Exchange Trigger Signal
  - Minimally Change Time Trigger Duration
  - Substantially Change Time Trigger Duration
  - Minimize/Maximize Time Trigger Durartion
  - Modify Change Trigger Expression
  - Exchange Call Trigger Method
- Guards:
  - Fix Guard Value
  - Invert Guard
  - Modify Guard Expression
- Effect:
  - Remove Effect
  - Exchange Effect Method
  - Modify Effect Body
- OCL:
  - Fix Expression
  - Negate Expression
  - Fix Subexpression
  - Negate Subexpression
  - Modify Boolean Operator
  - Modify Relational Operator
  - Modify Arithmetic Operator
  - Modify Set Operator
  - Modify Quantifier
- AGSL:
  - Remove Statement
  - Reorder Statement
  - Fix Parameter/Property
  - Modify Parameter/Property
  - Modify Operator
  - Fix Operand
  - Modify Operand
  - Fix Result

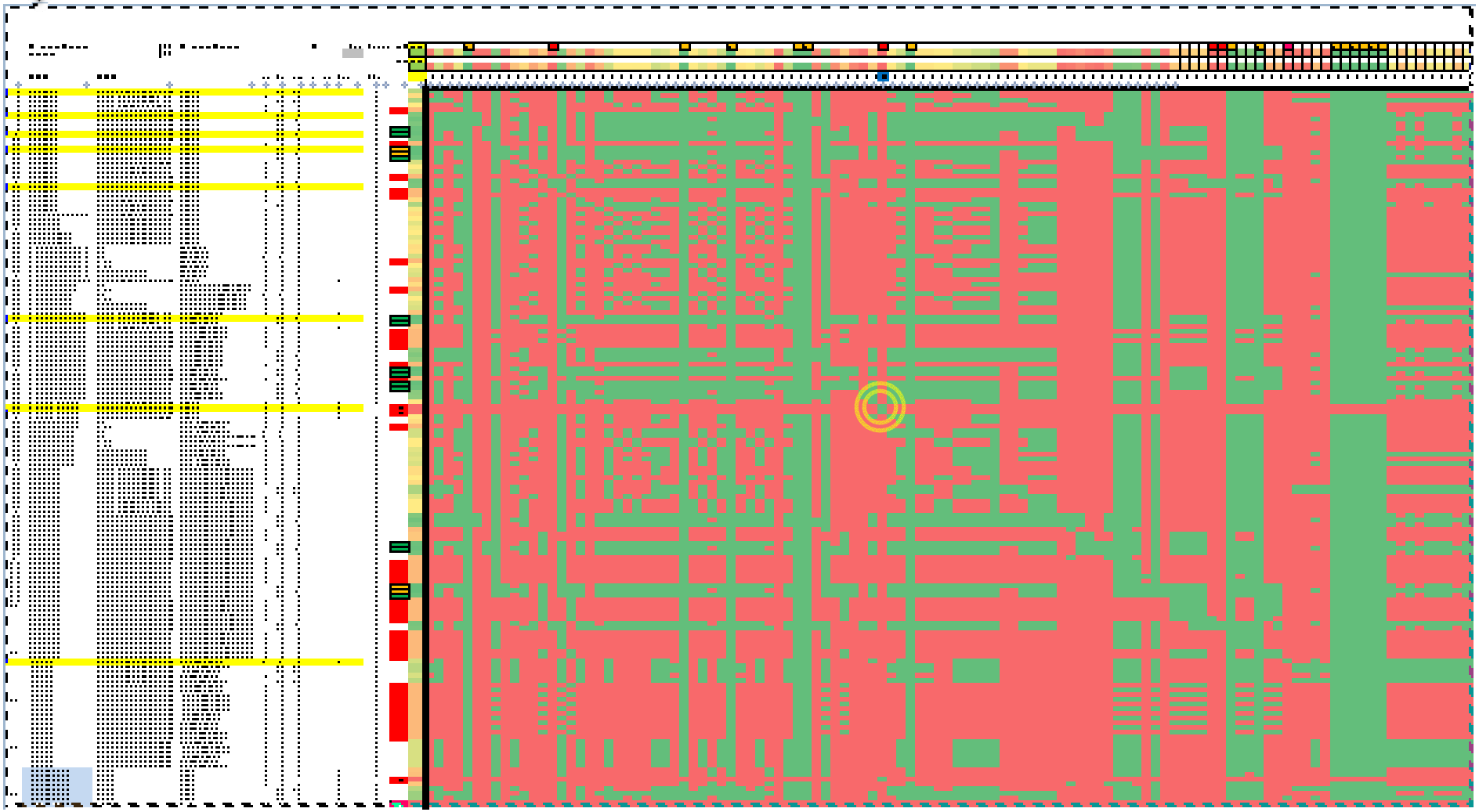
# Mutants and Test Cases

- 15 applicable mutation operators,
- 20 locations
- 111 mutants
- 152 generated test cases (minimal search depth)

| | **Manual Set** | **„Minimal“ generated set** |
|---|---|---|
| Source | 8 use cases | 8 mutants |
| I/O Steps | 70 | 137 |
| Accumulated time | 470s | 800s |
| Found mutants | 83 / 75% | 111 / 100% |

# Coverage overview

↓ Test cases → Mutants

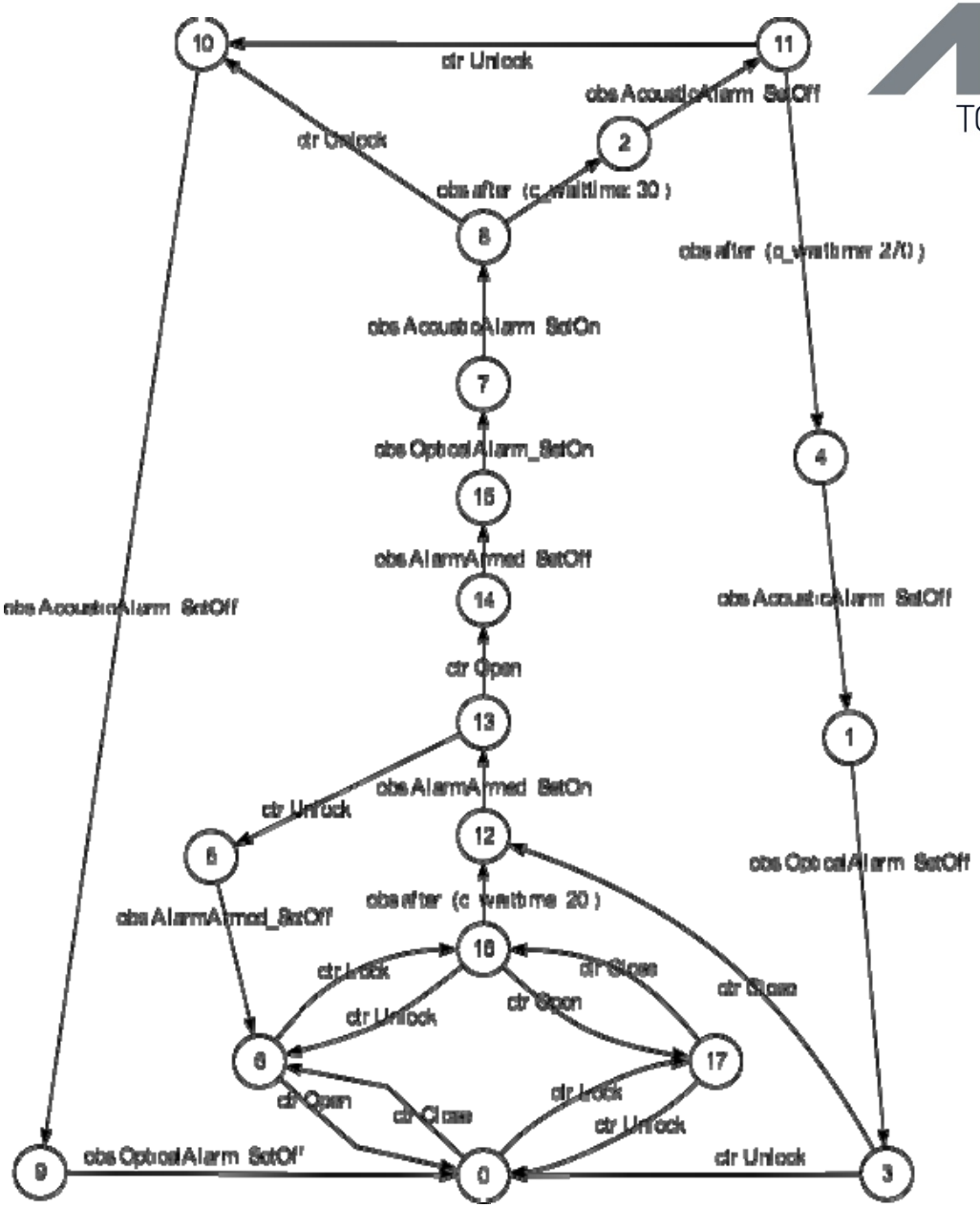


# Offene Themen / Nächste Schritte

- Skalierbarkeit
  - Symbolisch lösen
  - Model checking optimieren
  - Model splitting
- Effiziente Testfallsuiten
  - Auswahl Mutationsoperatoren
  - Erreichbarkeitsanalyse
  - Reihung Mutanten
- Äquivalente Mutanten
  - Heuristiken

# Backup

# Labeled Transition Systems (LTS)



# Input Output Conformance (ioco) (1)

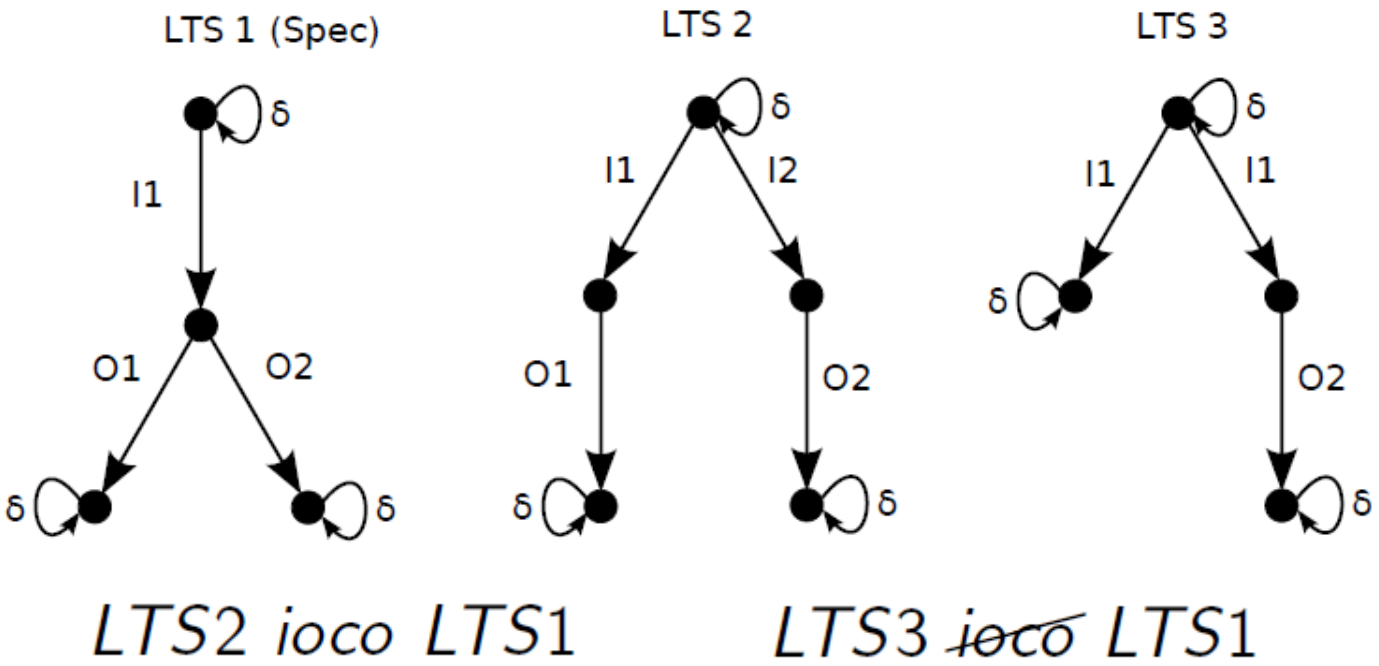
- Actions are partitioned into input $L_I$, output $L_U$, and internal events $\tau$
- $\delta$ denotes the observation that no output has occurred
- Implementations are input-enabled, i.e. an input cannot be blocked

$$i \textbf{ ioco } s =_{df} \forall \sigma \in Straces(s) \bullet$$
$$out(i \text{ after } \sigma) \subseteq out(s \text{ after } \sigma)$$

where Straces are defined over the alphabet $L_I \cup L_U \cup \{\delta\}$

# Input Output Conformance (2)

$$i \textbf{ ioco } s =_{df} \forall \sigma \in Straces(s) \bullet$$
$$out(i \text{ after } \sigma) \subseteq out(s \text{ after } \sigma)$$




*LTS2 ioco LTS1*  *LTS3 ~~ioco~~ LTS1*

# Figures

- Duration:
  - 36 (+3) months
    (Jan. 2008 – Dec. 2010)
- Costs:
  - 4,4 M€ Total
  - 3,1 M€ Funding
- Efforts:
  - 400,5 PM RTD
  - 48,5 Demo
  - 12,0 Mgmt
- Coordination:
  - AIT

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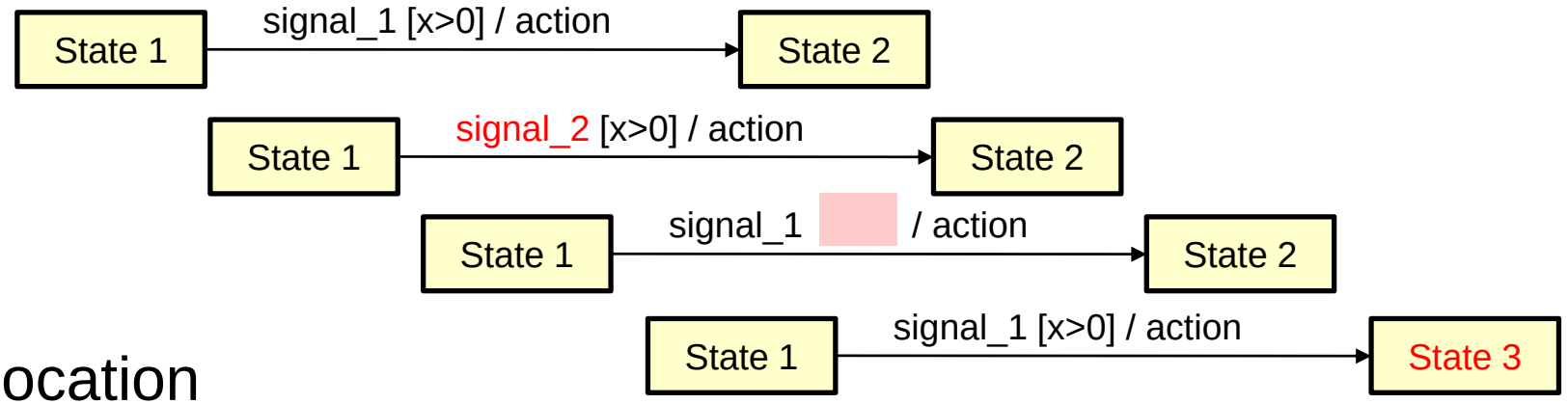
# Partner

- Universities
  - Budapest University of Technology and Economics (HU)
  - ETH Zurich (CH) / Stanford University (UK)
  - Graz University of Technology (AT)
- Research Organisations
  - AIT – Austrian Institute of Technology
  - SP Technical Research Institute of Sweden
- Industrial Demonstrators
  - Ford Forschungszentrum Aachen (DE)
  - Prolan Irányítástechnikai ZRT (HU)
  - Re:Lab S.R.L. (IT)
  - Thales Rail Signalling Solutions GmbH (AT)
- Tool Developer
  - Prover Technology AB (SE)

# Anatomy of a Mutation

Example: UML state diagram

- Mutation operators, e.g.:




- Location
  - affected model element
- Parameter
  - E.g. the new operator if an expression operator is changed

# Abstract Test Case

Example:

| | |
|---|---|
| 1. Ctrl : Alarm sensor off | initialisation |
| 2. Ctrl : Lock the vehicle | … |
| 3. after(20) | … |
| 4. Obsv : AlarmArmed SetOn | observed signal |
| 5. Ctrl : Alarm trigger | alarm event |
| 6. Obsv : AlarmArmed SetOff | expected reactions |
| 7. Obsv : OpticalAlarm SetOn | … |
| 8. Obsv : AcousticAlarm SetOn | … |
| 9. after(30) | after 30 seconds |
| 10. Obsv : AcousticAlarm SetOff | acoustic alarm switches off |
| 11. Ctrl : Unlock | unlock the car |
| 12. Obsv : OpticalAlarm SetOff | optical alarm switches off |