TRACKING DYNAMICS IN CONCURRENT DIGITAL TWINS

CSD&M 2018

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Synopsis
- ~55 staff members, many with extensive industrial experience
- 5 Part-time Professors
- Working at industry locations
- Program turnover 2017: ~10Mio €

Technology Profile
- Cyber Physical Systems
- Multi-disciplinary system overview
- System analysis and system synthesis
- Model driven engineering

Mission: To advance industrial innovation and academic excellence in embedded systems engineering

* TNO = the Netherlands Organisation for applied scientific research
DIGITAL TWIN

Executable model that takes real data as inputs
CHALLENGE IN HIGH TECH INDUSTRY

CONSTRUCTION
- Complex systems
- Integrated systems
- System of systems

USE
- Changing machines
- Changing factories
- Changing usages

HUGE MODELS

MANY CHANGES

MODEL MAINTENANCE CHALLENGE
1. Detect change
2. Localize change
3. Locally adapt

Domain Specific Language supporting

Modular way-of-working supporting constraints
DETECT CHANGE

Probability of Finding

How likely is it that we observe the data according to the model.
BAYESIAN BELIEF NETWORK

CONSTRUCTION
- Experts provide structure
- Experts provide numbers
- Structure learned from data
- Numbers learned from data

USE
- Deal with uncertainty
- Different scenarios
- Explains outcome
- Numbers have meaning
- Handles missing data

Encodes a joint probability distribution

Provides the Probability of Finding automatically
• Based on Western Electric Rules for statistical process control

- **Rule 1**: Any point beyond Zone A
- **Rule 2**: Two out of three consecutive points fall Zone A or beyond
- **Rule 3**: Four out of five consecutive points fall Zone B or beyond
- **Rule 4**: Nine consecutive points on the same side of center line (mean)

• Adapted to take *probabilities* as observations
Calculate Probability of Finding *per fragment*

How *likely* is our observation of the *fragment data*, according to the model, and given the observations in the rest of the model
EXPERIMENTAL VALIDATION

Change 1
Generate data

Change 2
Generate data

Change 3
Generate data

What happened when?

Hide ground truth

An initiative of industry, academia and TNO
FRAGMENT RULES

Principles: Causality, Causal Sufficiency, and Faithfulness on Suitable Variables

The Causal Markov Condition states that a phenomenon is independent of its non-effects, given its direct causes. The Markov condition (a.k.a. Markov assumption) for a Bayesian network states that any node in a Bayes net is conditionally independent of its non-descendants, given its parents. If the structure of a Bayesian network depicts causality, the two conditions are equivalent, which provides a test for causality.

A node is conditionally independent of the remaining network, given its Markov blanket.

The Markov blanket of node includes its parents, children and the other parents of all its children. The parents of children are included, as they can explain away effects.

The Markov blanket provides a suitable notion on the locality of cause-effect relationships. A causal fragment should not extend beyond the Markov blanket of a topic’s core node, if such exists.

A structure, like that of a Bayesian network fragment, is causally sufficient if there is no common cause that is outside the structure which impacts variables within it. Models that are not causally sufficient typically fail the Markov Condition.

Variables are appropriately distinct. They capture independent observables, causes, or effects individually.

Variable states are not too coarsely grained, as they must capture distinct causes / effects.

Applied principles
The theory unfurls from principle 1 to 6, but checking a Bayes net for modularization starts with 5 and 6. Given those, the structure conditions 3 and 4 must be fulfilled. 1 and 2 guide towards sensible fragments.

These requirements allow localized change in the network structure.

Are these restrictions really limiting??

An initiative of industry, academia and TNO
SUMMARY

- Modular model design method
- Fragmentation rules
- Probability of Finding tracking

MAINTAINABLE MODELS

How to maintain?
THANK YOU

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Join our ESI Symposium, Eindhoven NLD, Tuesday April 9, 2019
Theme: Intelligence – the next challenge in system complexity?