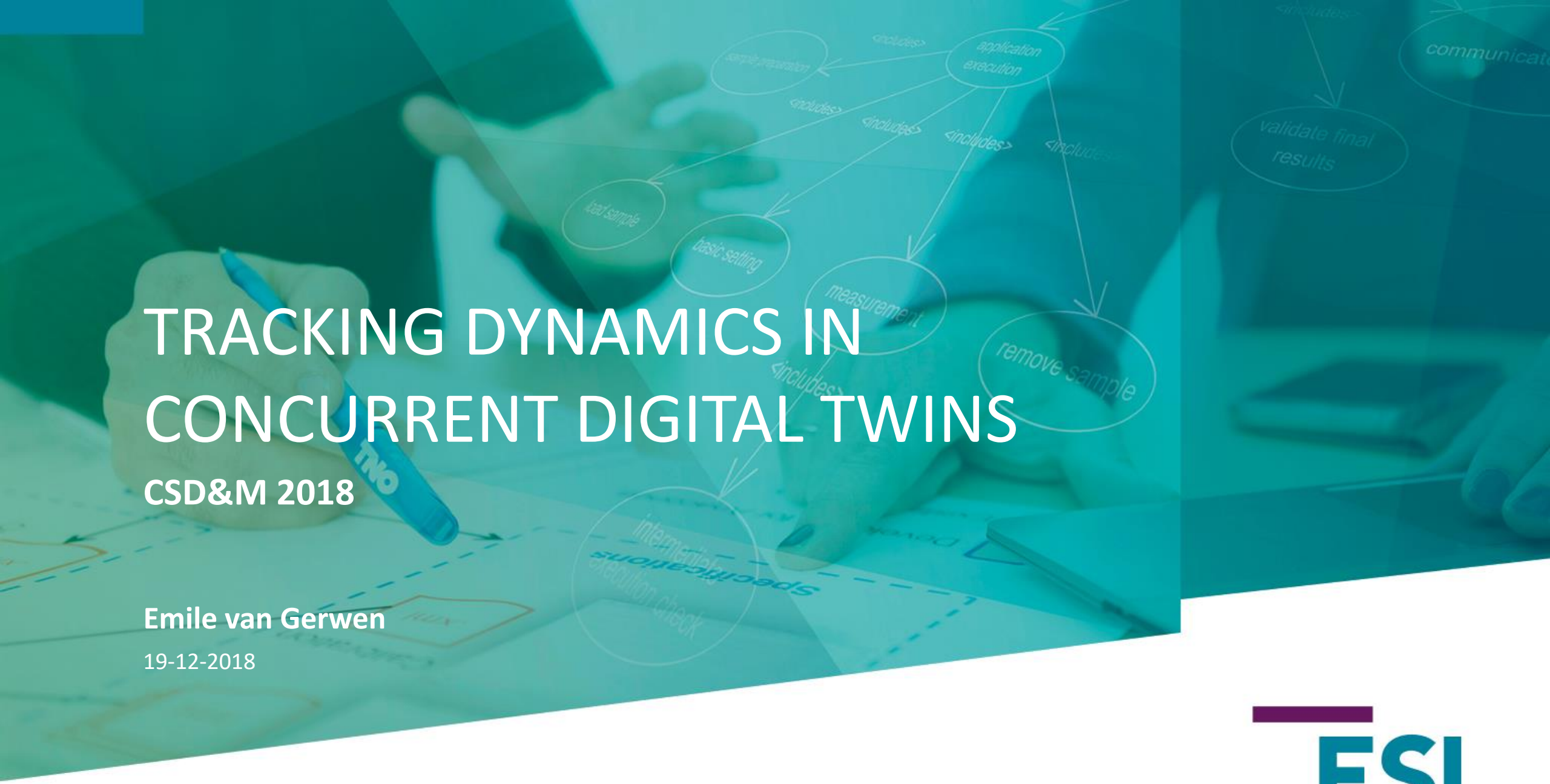


TRACKING DYNAMICS IN CONCURRENT DIGITAL TWINS

CSD&M 2018

Emile van Gerwen

19-12-2018

An initiative of industry, academia and TNO

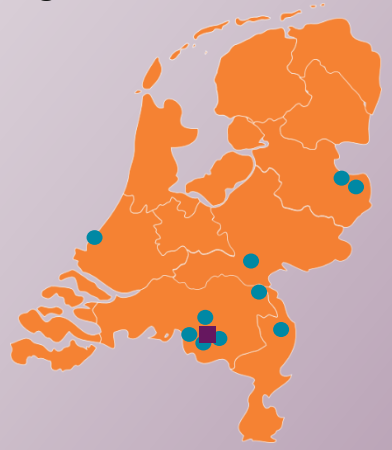
ESI

ESI: HOSTED BY TNO* IN PARTNERSHIP WITH HIGH-TECH INDUSTRY AND UNIVERSITIES

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

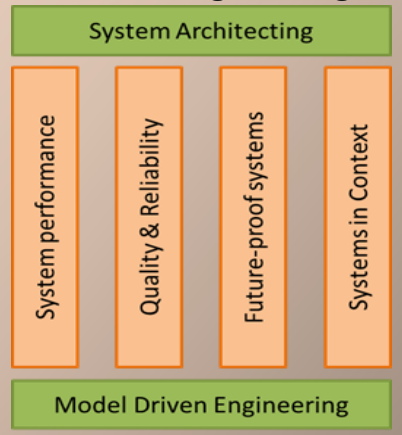
Synopsis

- ~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

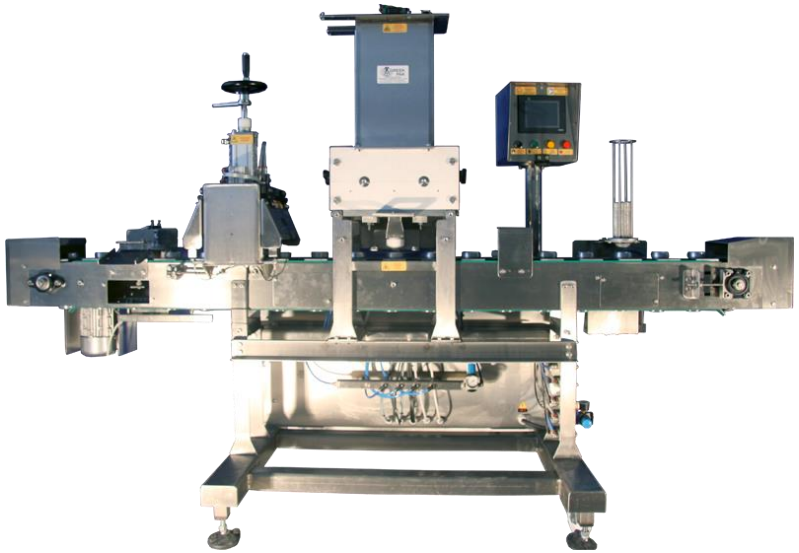


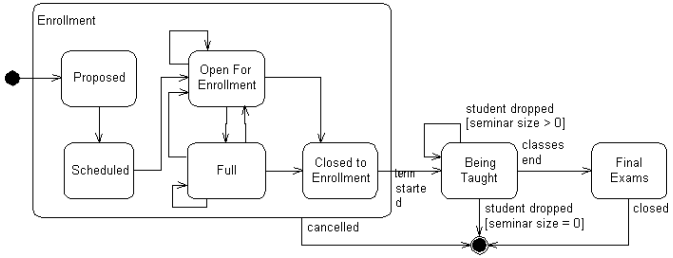
Partners

ASML PHILIPS
THALES océ
ThermoFisher SCIENTIFIC A CANON COMPANY
TU/e technische universiteit eindhoven
TU Delft Delft University of Technology
NXP
Radboud University
TNO
UNIVERSITY OF TWENTE.

* 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

Domain Specific Language

MODEL MAINTENANCE CHALLENGE

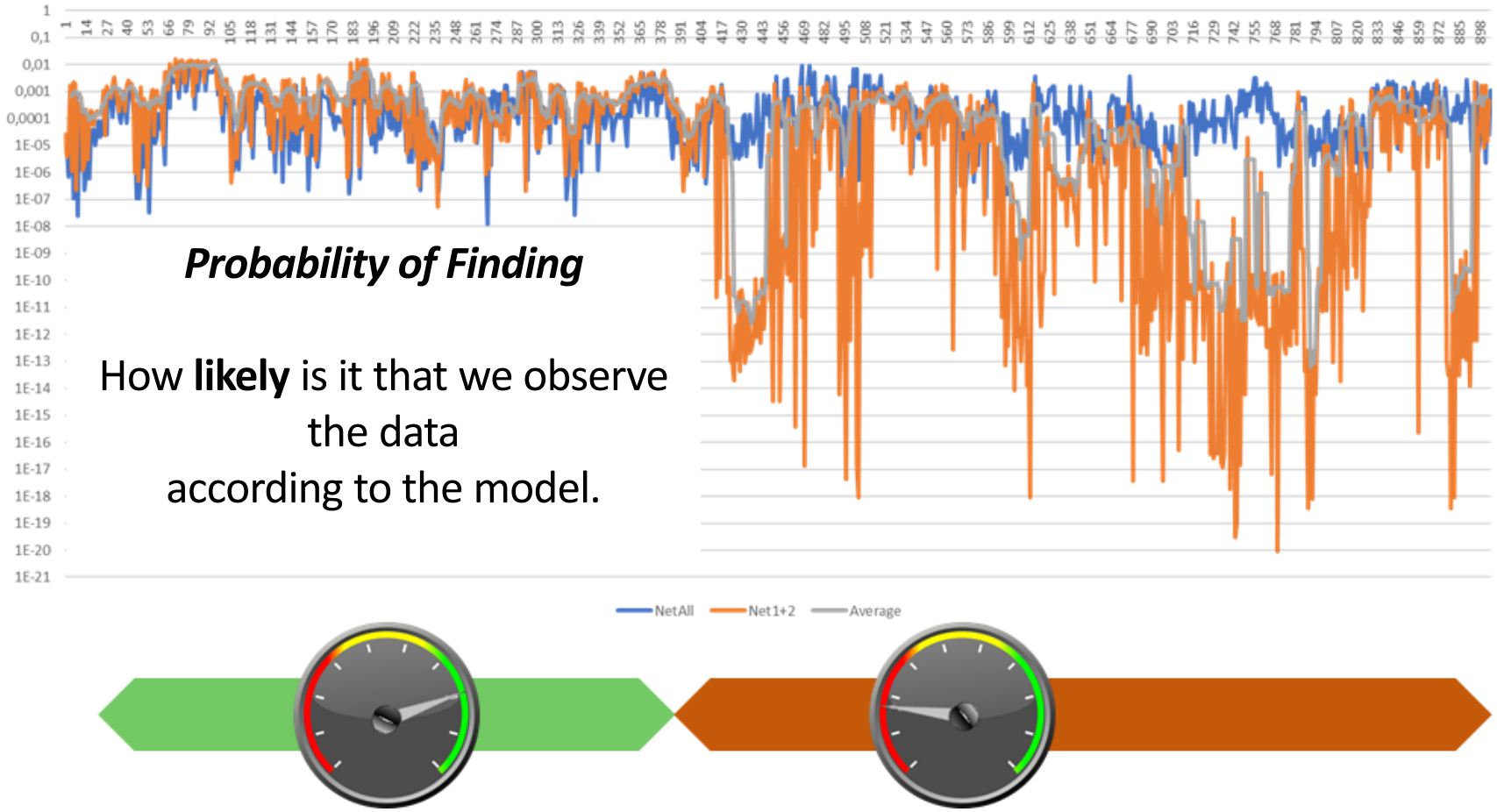
supporting

1. Detect change
2. Localize change
3. Locally adapt

Modular way-of-working

constraints

DETECT CHANGE



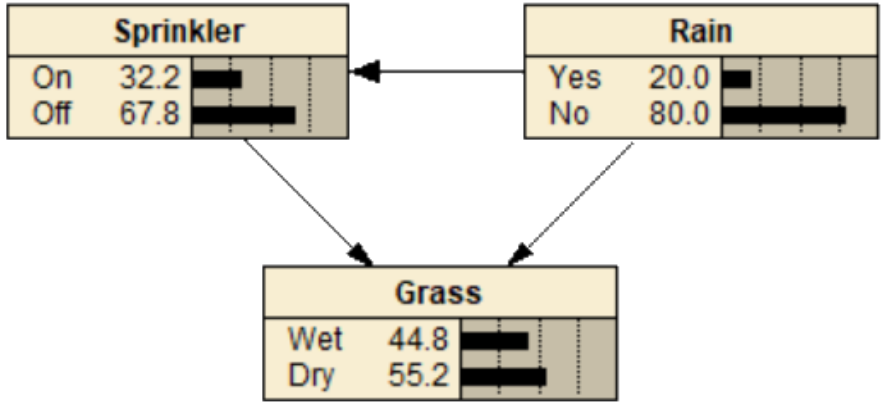
Probability of Finding

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



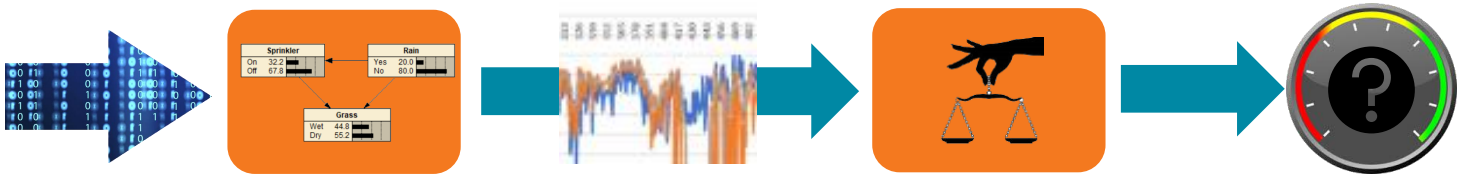
USE

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

Encodes a joint probability distribution

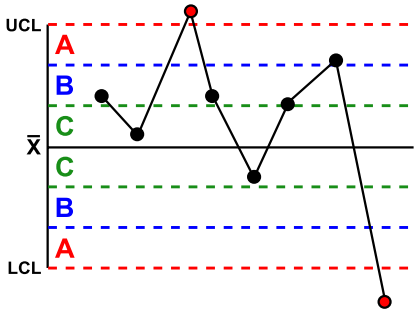
Provides the Probability of Finding automatically

DETECTOR

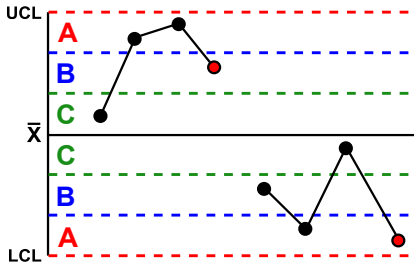


- Based on Western Electric Rules for statistical process control

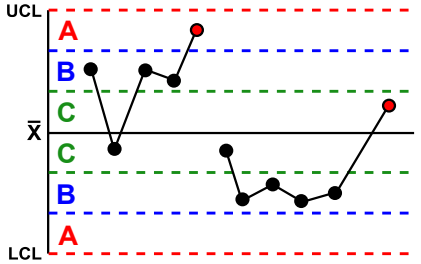
Rule 1: Any point beyond Zone A



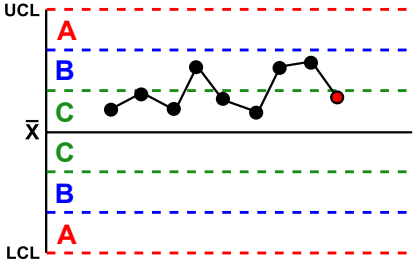
Rule 2: two out of three consecutive points fall Zone A or beyond



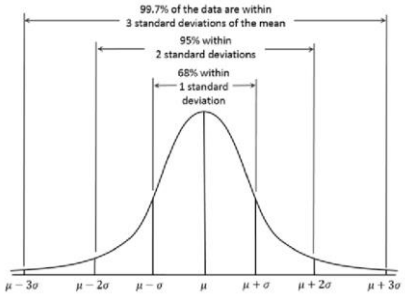
Rule 3: Four out of five consecutive points fall Zone B or beyond

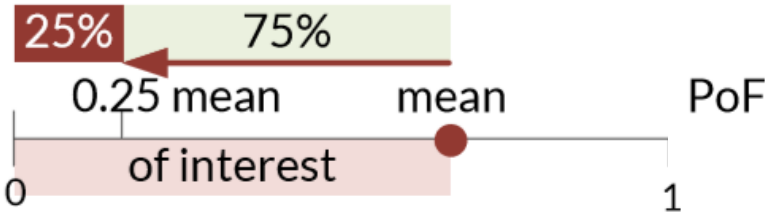


Rule 4: Nine consecutive points on the same side of center line (mean)



- Adapted to take *probabilities* as observations

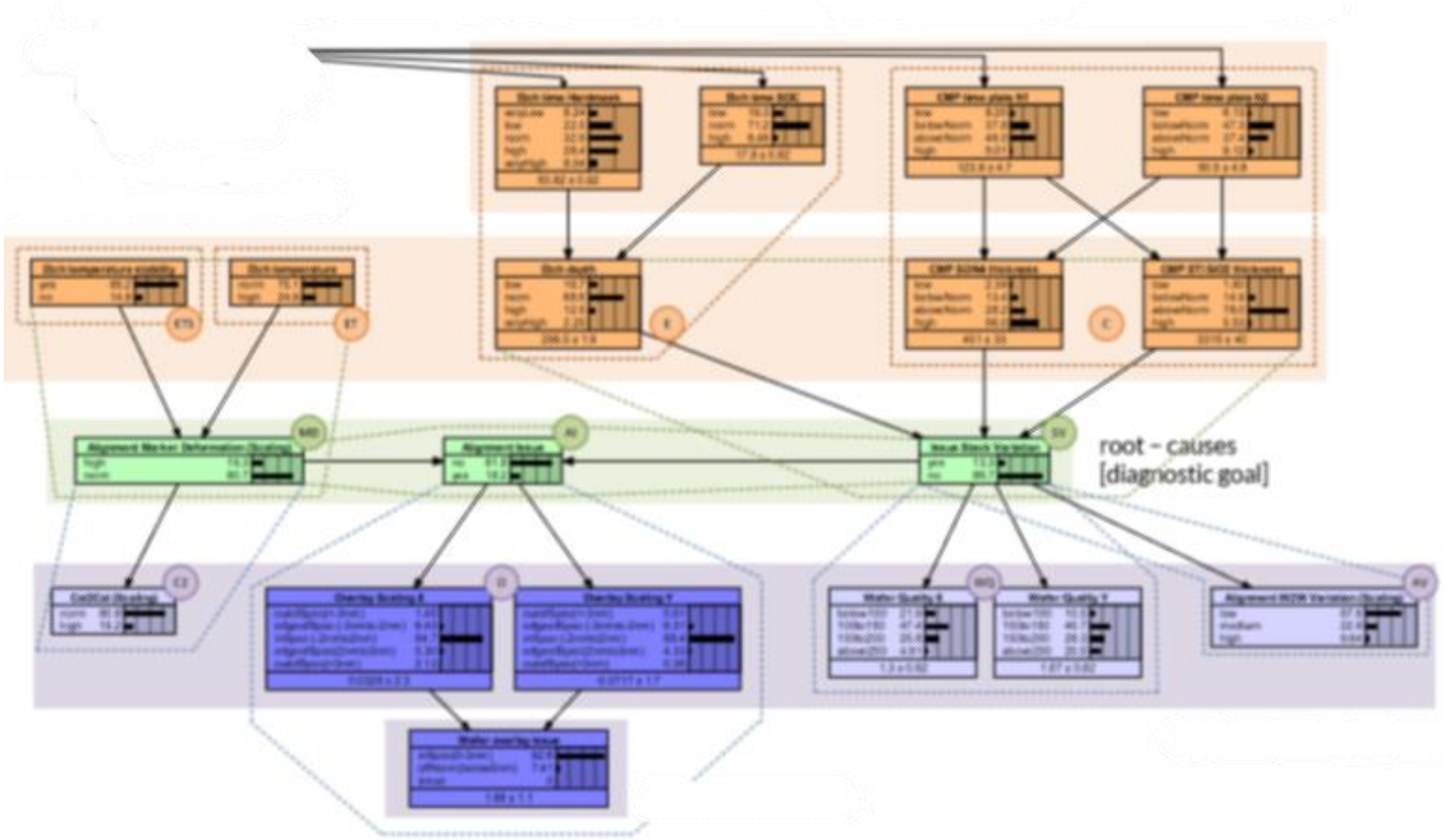




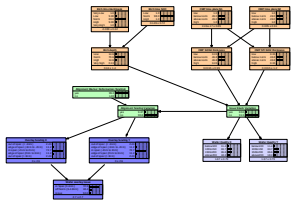
LOCALIZE CHANGE

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

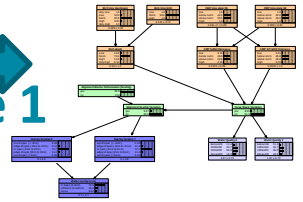


EXPERIMENTAL VALIDATION



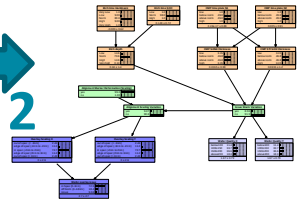
Generate data

Change 1



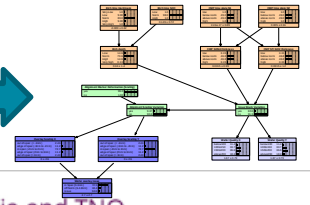
Generate data

Change 2

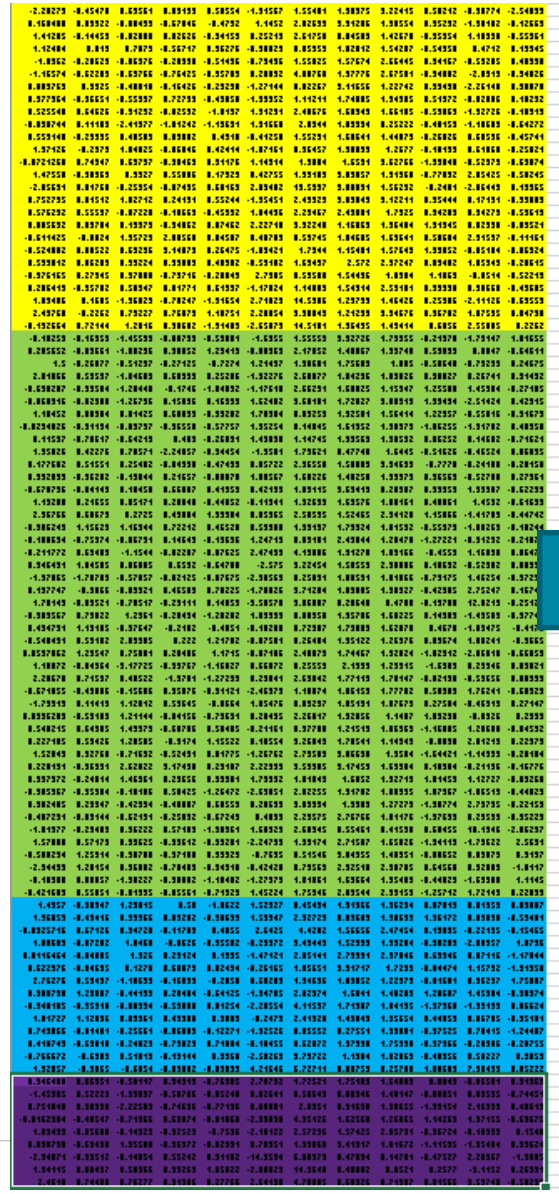


Generate data

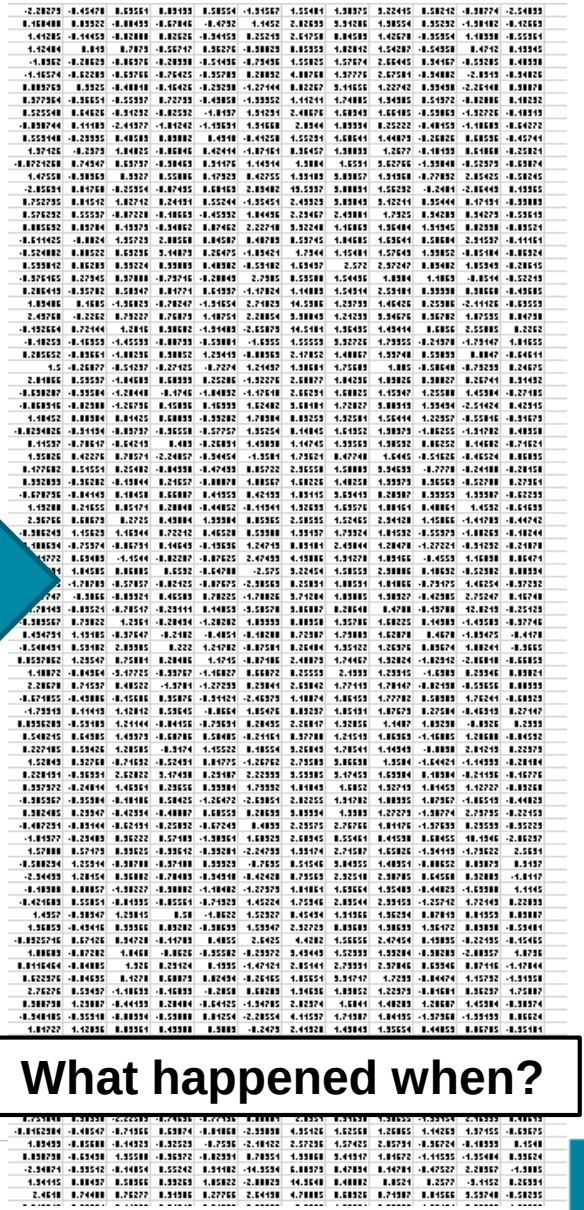
Change 3



Generate



Hide ground truth



What happened when?

An initiative of industry, academia and TNO

FRAGMENT RULES

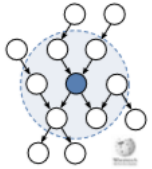
Principles: Causality, Causal Sufficiency, and Faithfulness on Suitable Variables

1. 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.

2. 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 of 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.

3. 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 in.

   Models that are not causally sufficient typically fail the Markov Condition.

OK

4. A structure, like that of a Bayesian network fragment, is **faithful** if and only if all of the conditional and unconditional probabilistic independencies that exist among the variables are included in the structure.

   The Faithfulness Condition implies that the causal influences of one variable on another along multiple causal routes does not 'cancel'.

OK

unshielded collider

not OK

alternate pathway can cancel effect

5. Variables are appropriately **distinct**.

   They capture independent observables, causes, or effects individually.

OK

not OK

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

Applied principles

The theory unrolls 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??

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?