Concept Drift Detection with Variable Interaction Networks

Eurocast 2019, 18/02/2019

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Smart Factory Lab, IWB 2014 – 2020, www.smartfactorylab.at/en

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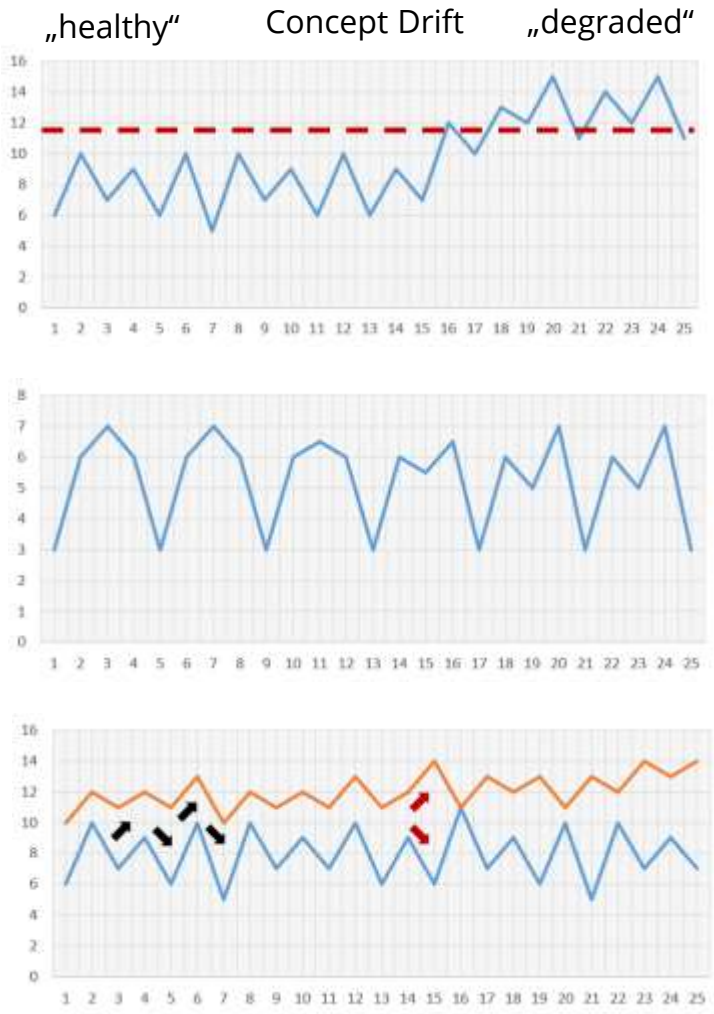
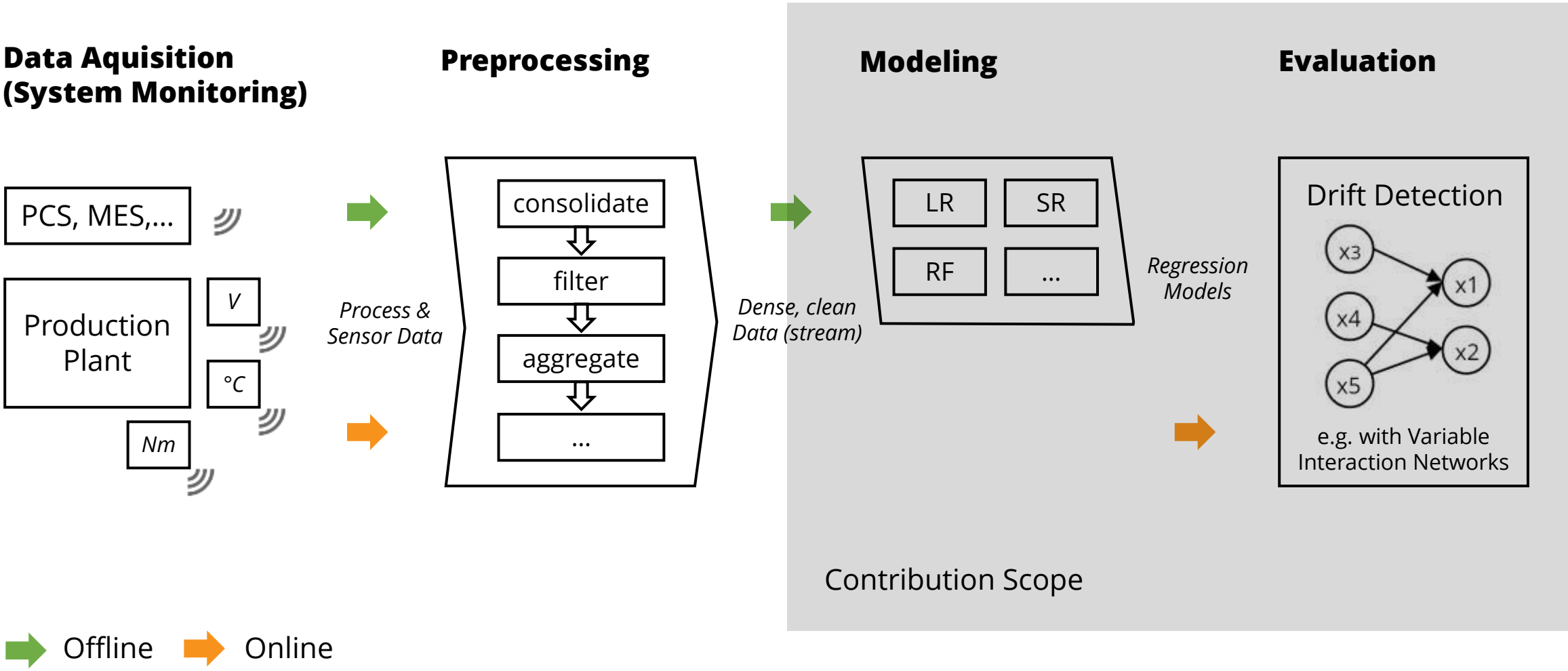
Research Question:
How can we adapt meta-heuristic algorithms for Predictive Maintenance (PdM)?

Challenges

- Quality of recorded data
  - Frequency, accurracy, amount,...
  - Supervised learning needs supervised recording
- Deployment and real-time evaluation
- Realistic goals
  - Prediction of *Remaining Useful Lifetime* is difficult
  - First Step: Detection of states and deviations



Data Based PdM Approach



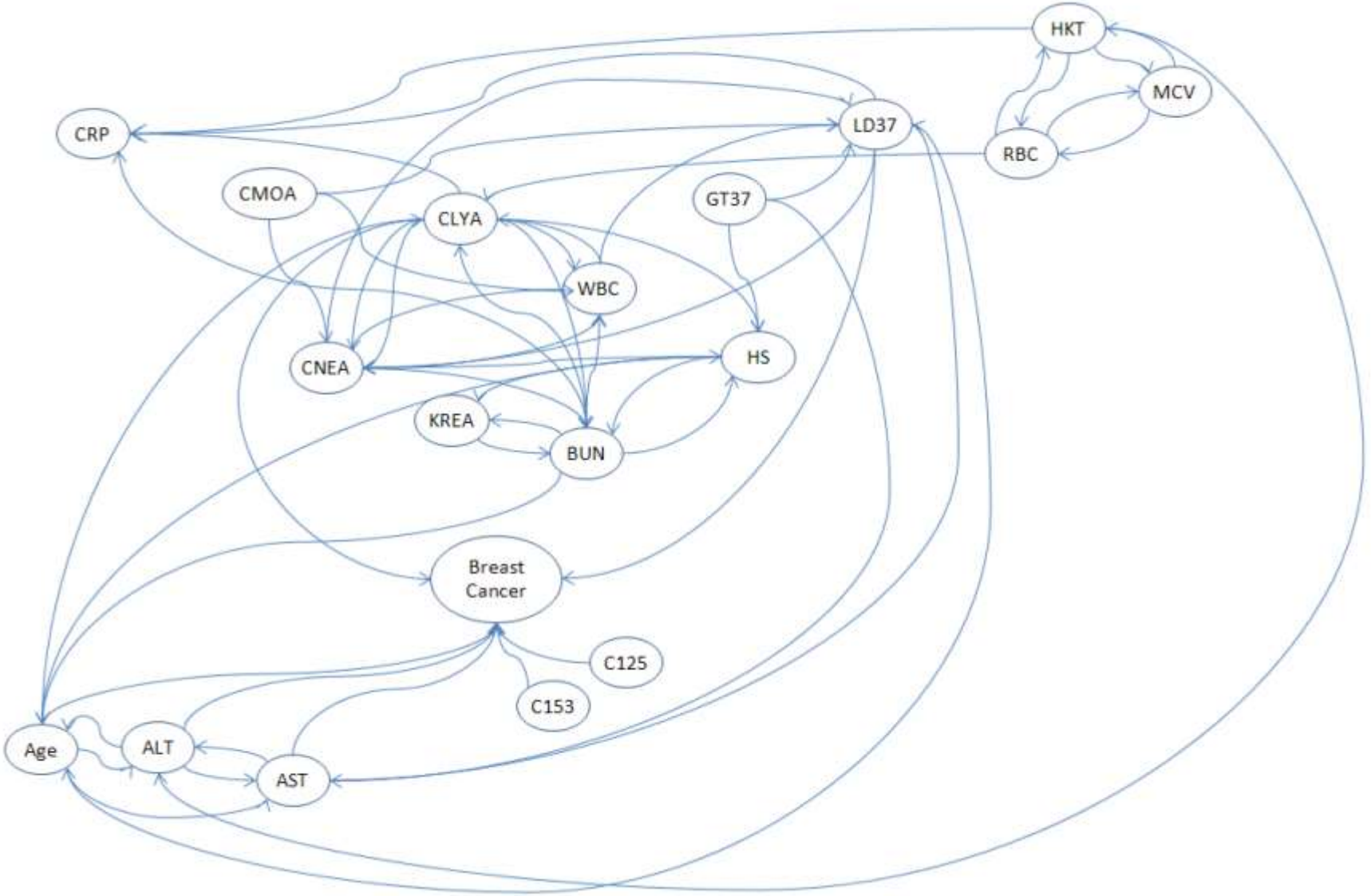
Variable Interaction Network

= directed, weighted graph

(nodes: variables, edges: impact of variables on others)

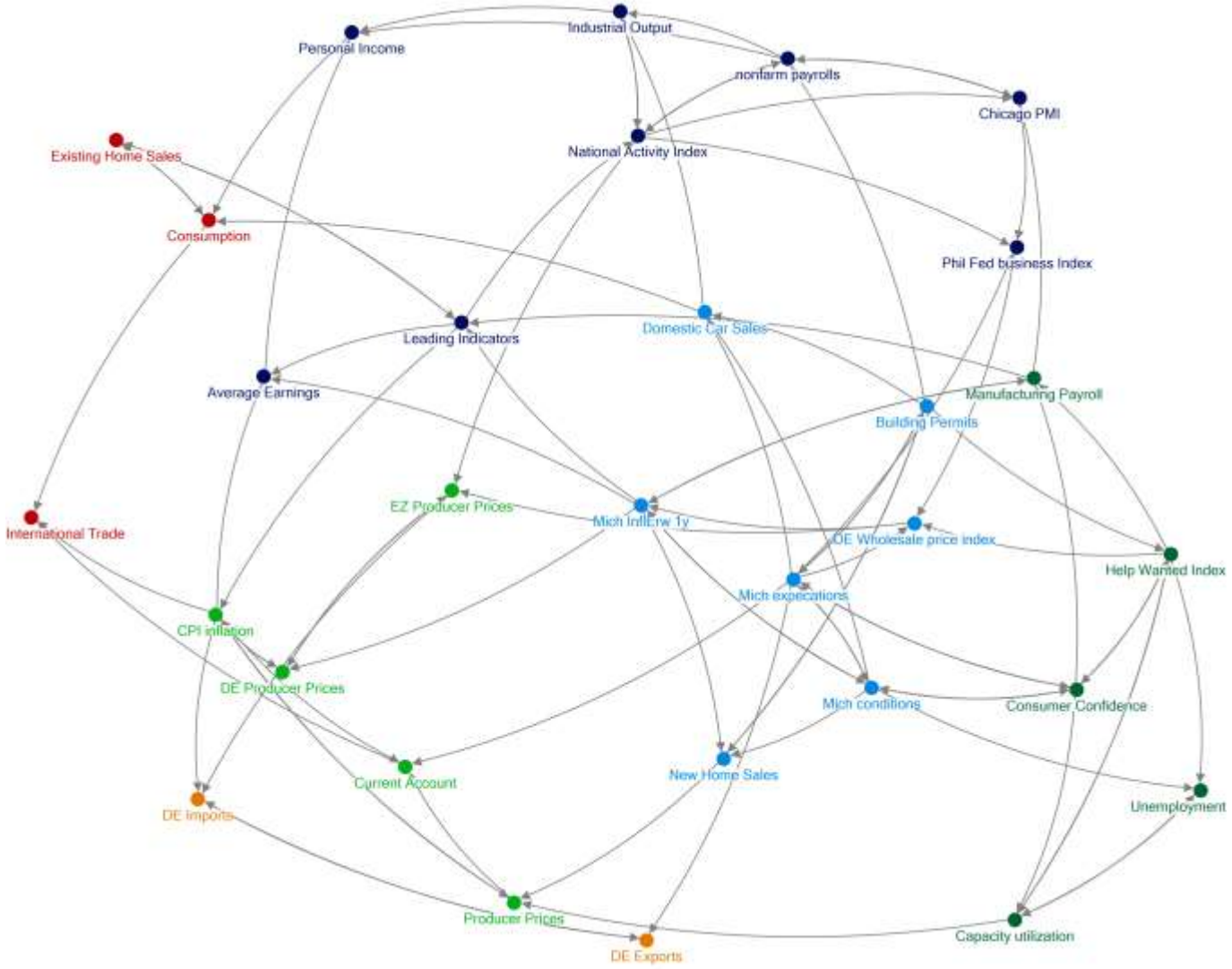
- Model Type Characteristics
  - ↖ Enables holistic system analysis
  - ↖ Agnostic to the regression algorithms which are used as base
  - ↖ Fast to build, once regression models are built
  - ↙ Non-deterministic modeling may result in many different network alternatives
  - ↙ Infeasible for high-dimensional data without pruning

Sample Variable Interaction Network



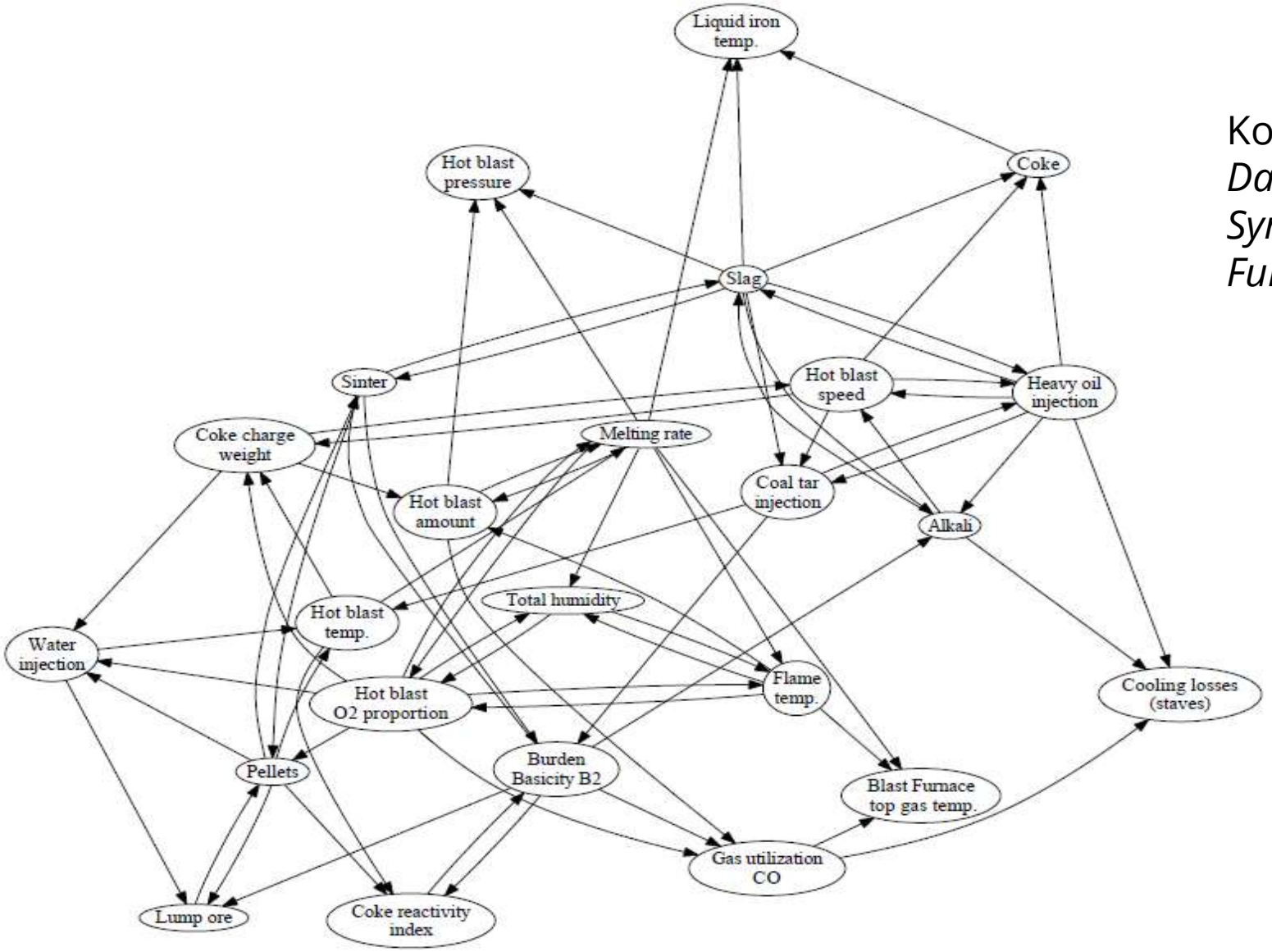
Winkler et al.
Variable Interaction Networks in Medical Data.
EMSS, 2012

Sample Variable Interaction Network



Kronberger et al.
Genetic Programming: Current Trends and Applications in Computational Finance,
Nova Science Publishers, 2013

Sample Variable Interaction Network



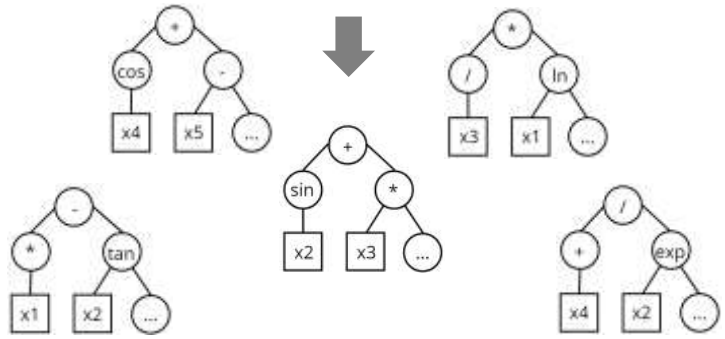
Kommenda et al.,
Data Mining using Unguided Symbolic Regression on a Blast Furnace Dataset. EvoComplex, 2011

Variable Interaction Network: **Modeling**

1. Alternate targets & inputs

target | input variables

x1	x2	x3	x4	x5
1.1	1.4	1.7	1.3	1.2
1.2	1.3	1.4	1.5	1.3
1.2	1.1	1.4	1.9	1.4
1.4	0.9	1.2	1.3	1.4
1.2	1.2	1.6	1.2	1.7



2. Calculate variable impacts

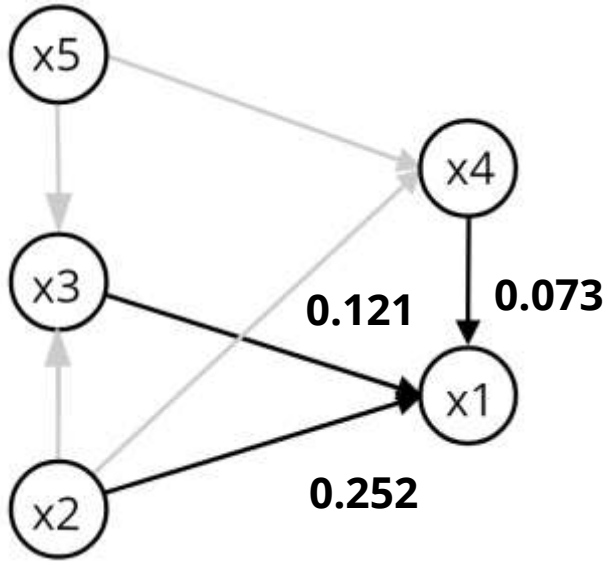
2.1 Replace variable values, e.g. by shuffling

2.2 Recalculate model error, e.g. R^2
→ Error increment = impact

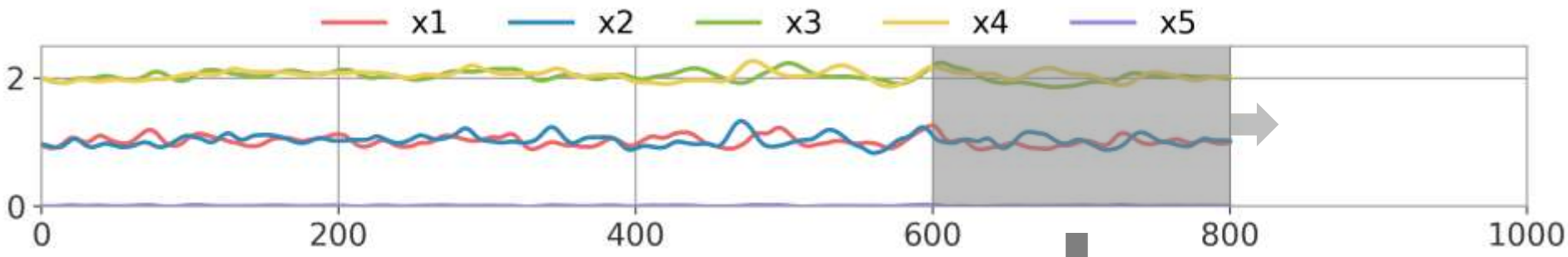
Example calculation for x1:

Variable	Impact for x1
x2	0.252
x3	0.121
x4	0.073
x5	0.037

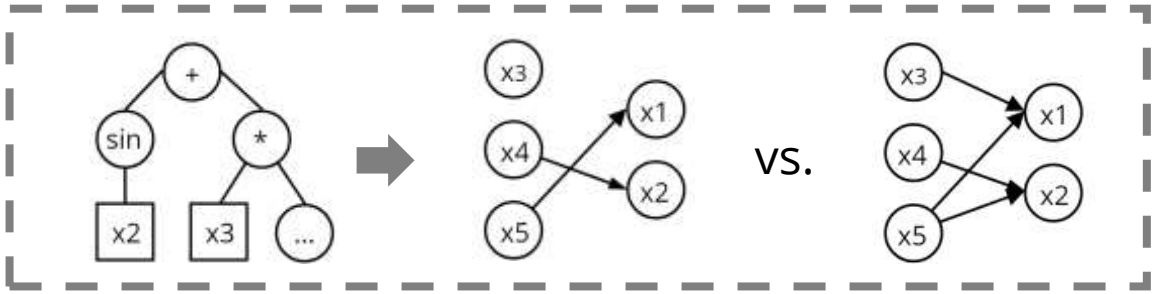
3. Create network



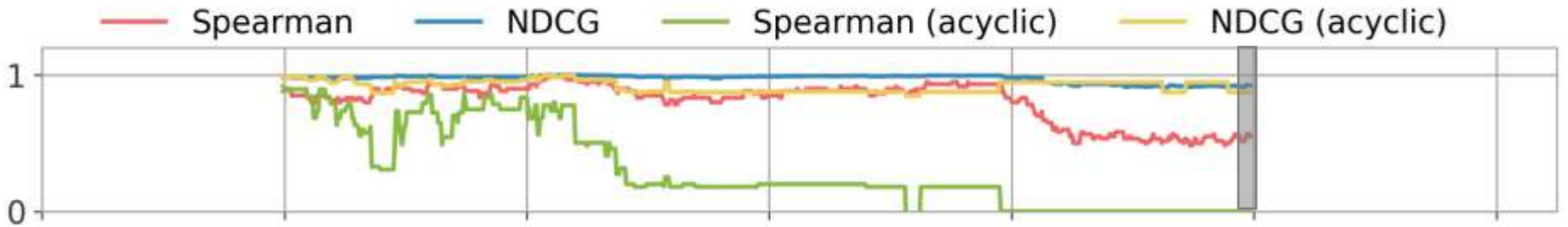
Variable Interaction Network: **Evaluation**



Current Net



Initial Net



Variable Interaction Network: **Comparison**

Initial Net:

	x1	x2	x3
x1		0.7	0.3
x2	0.2		0.4
x3	0.3	0.3	

vs.

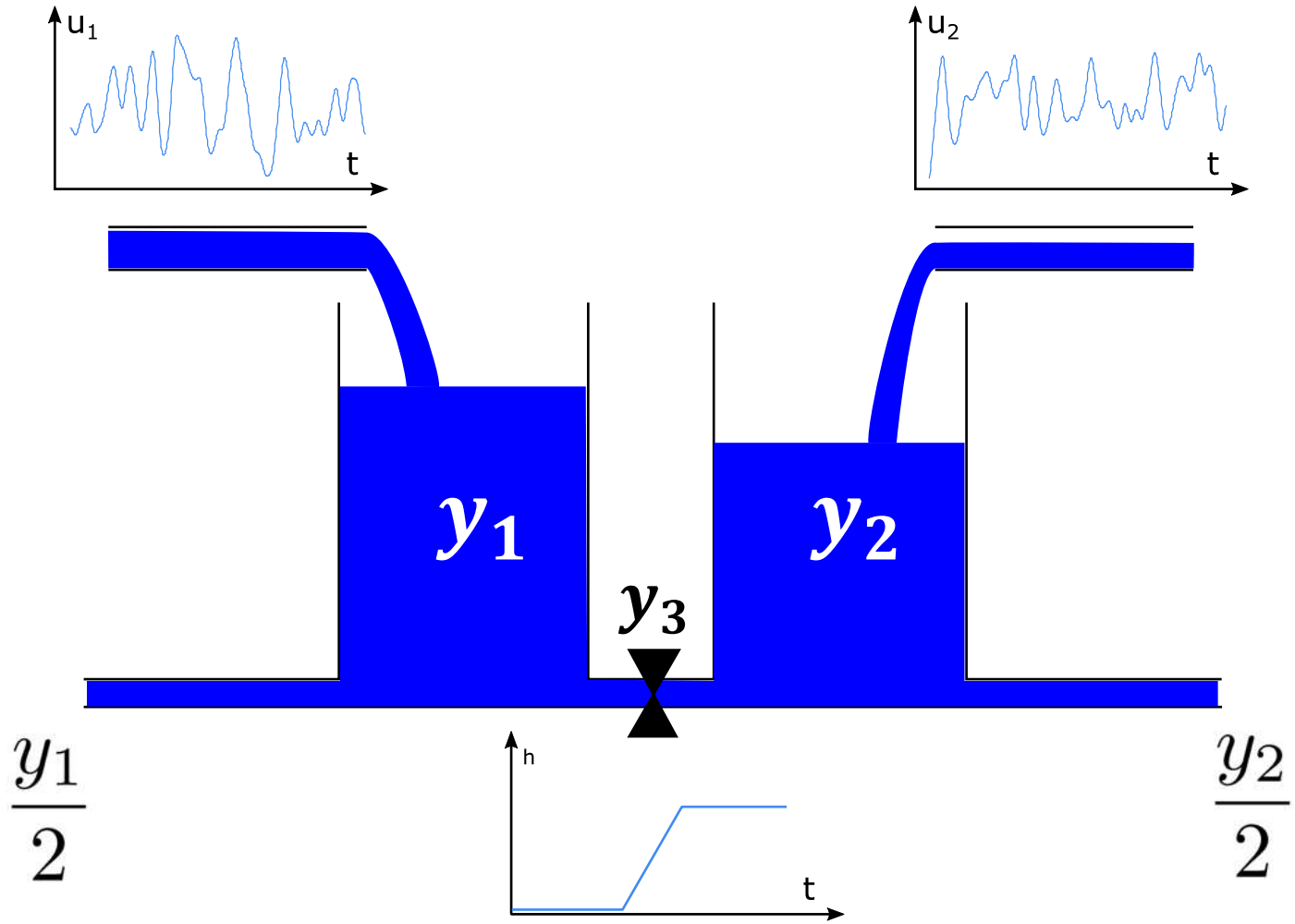
Current Net:

	x1	x2	x3
x1		0.5	0.4
x2	0.1		0.7
x3	0.2	0.6	

- **Spearman's Rank Correlation**
  Considers deviations in ranks, top-ranked variables are treated equally to lowly ranked variables.
- **Normalized Discounted Cumulative Gain [Kekäläinen, 2002]**
  Exponential weighting scheme which puts more weight on top-ranked variables (developed in the context of information retrieval).

Kronberger et al., Measures for the Evaluation and Comparison of Graphical Model Structures, Eurocast 2017

Toy Problem: Communicating Vessels



$$\frac{y_1}{2}$$

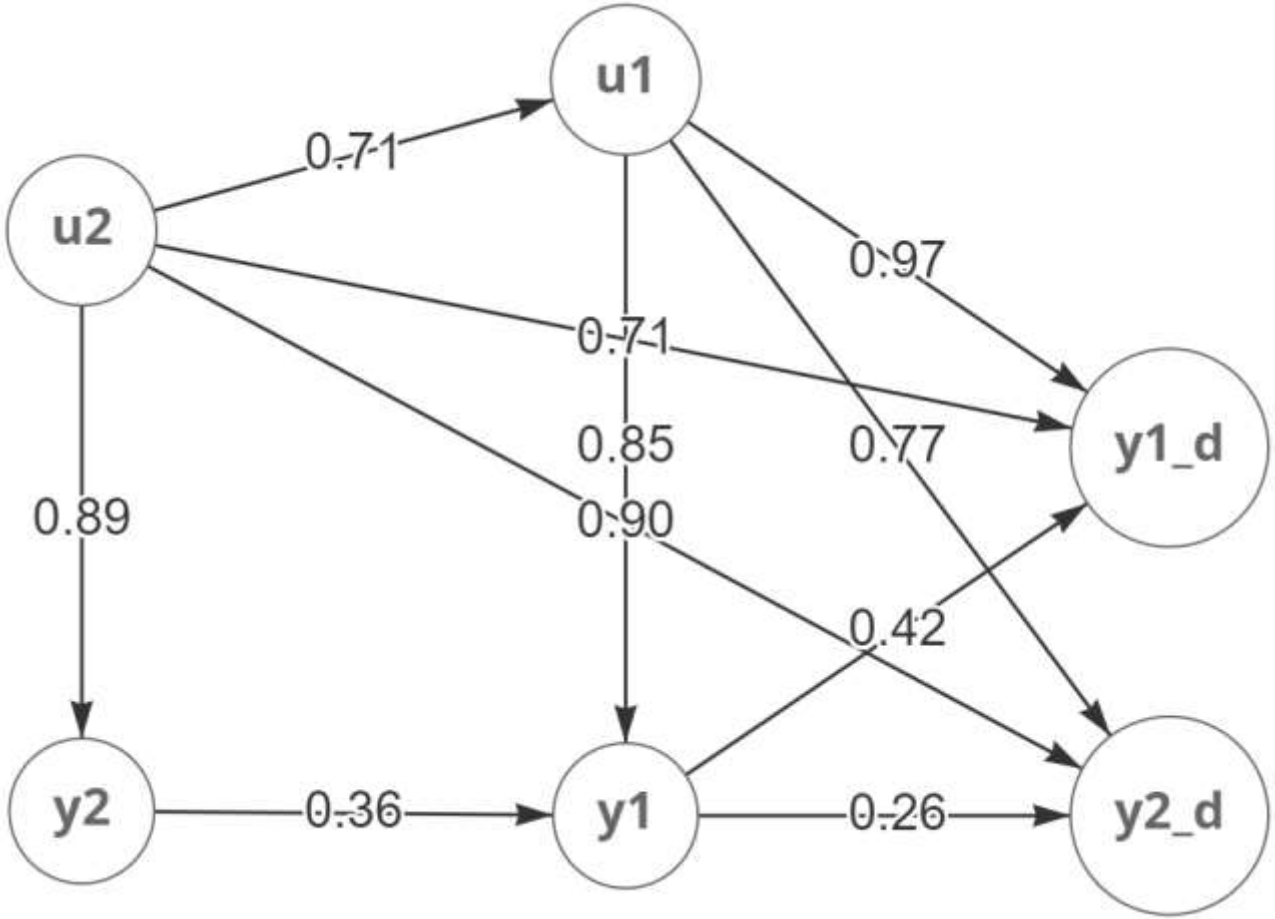
$$\frac{y_2}{2}$$

$$\dot{y}_1 = u_1 + y_3 - \frac{y_1}{2}$$

$$\dot{y}_2 = u_2 - y_3 - \frac{y_2}{2}$$

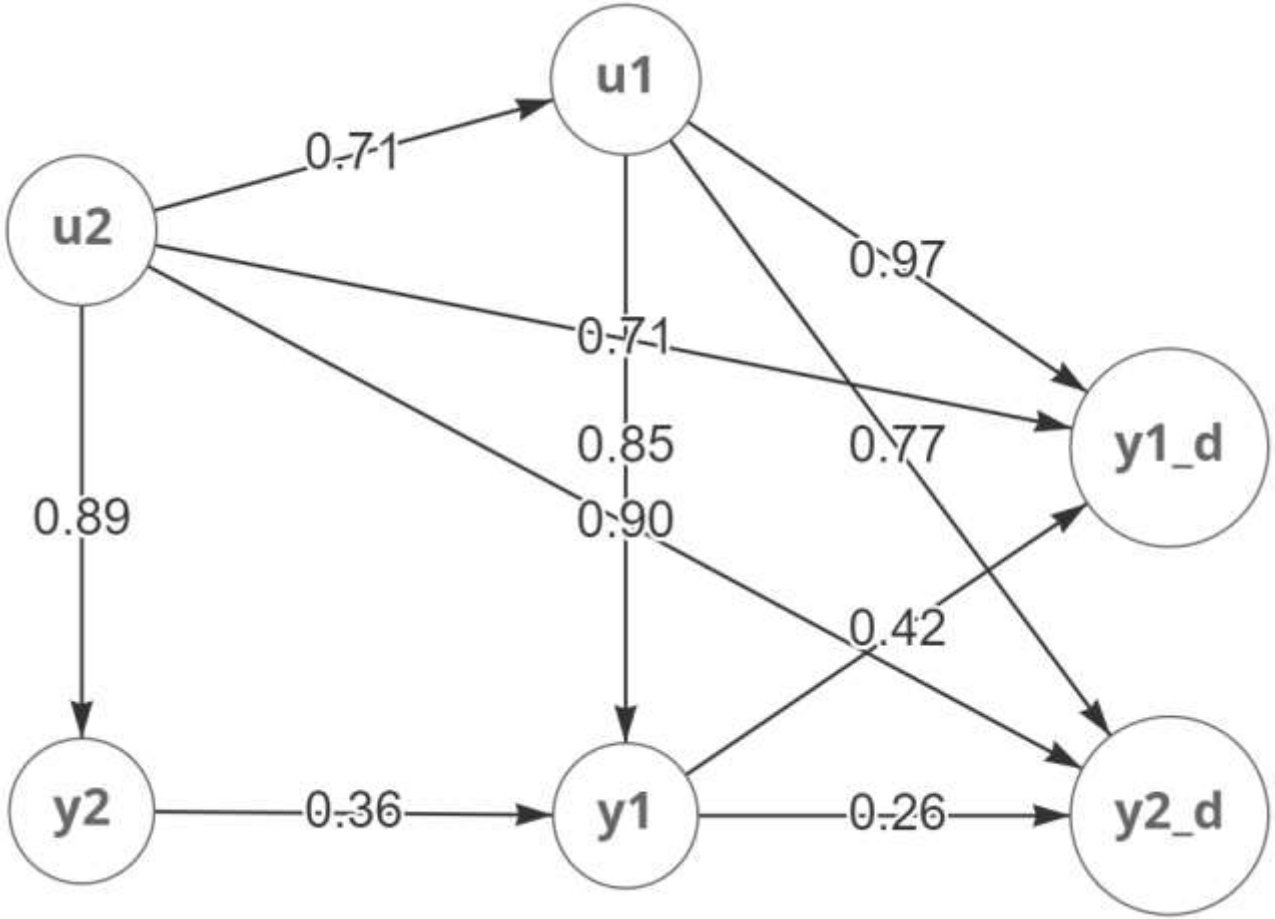
$$\dot{y}_3 = -(y_1 - y_2) - hy_3$$

Brief Live Demo



Toy Problem: Communicating Vessels

Trained Network



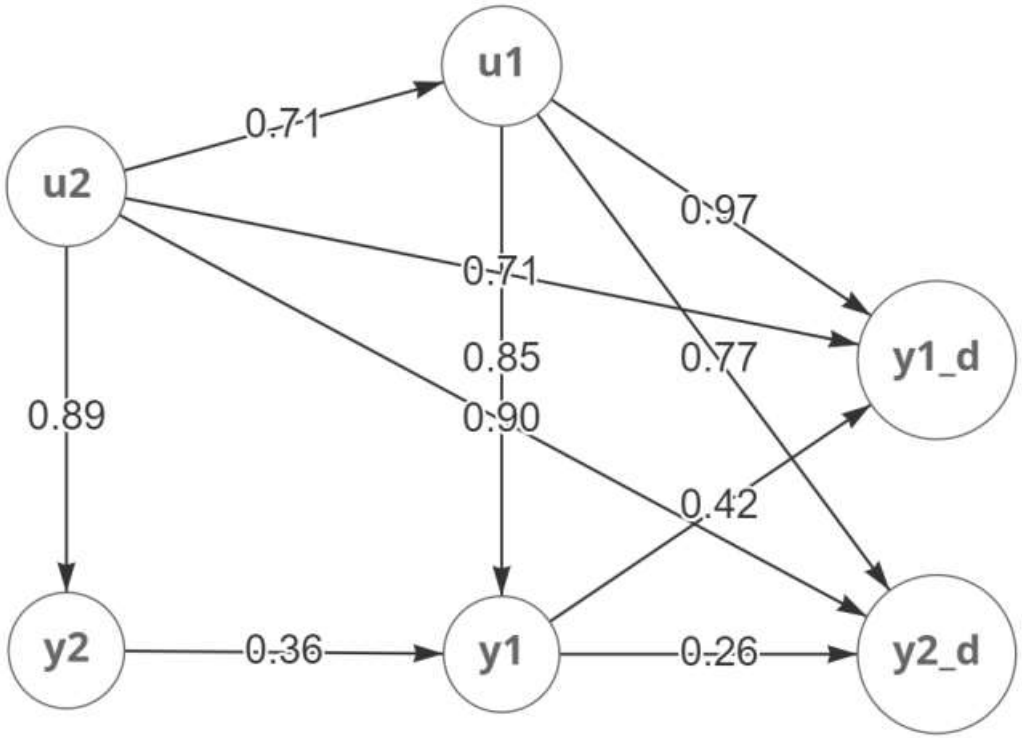
Sample Run:

Modeling: Symbolic Regression (SR), Evaluation: Sliding Window Size = 200

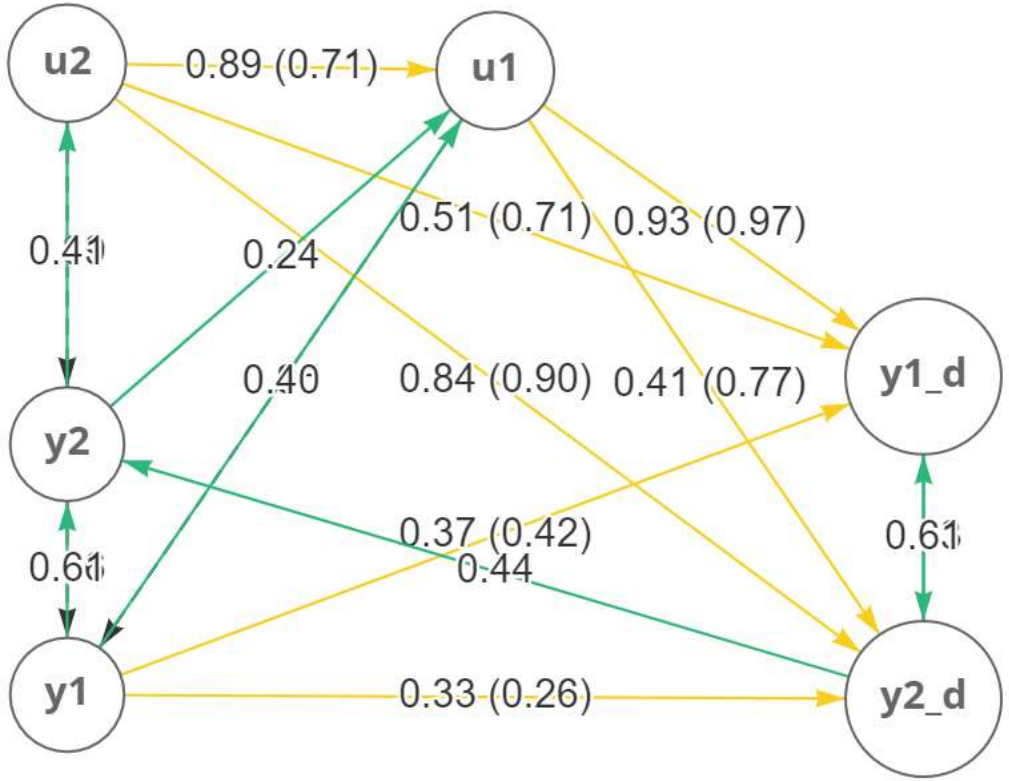
Toy Problem: Communicating Vessels

Network Snapshots

Network „0“



Network „525“



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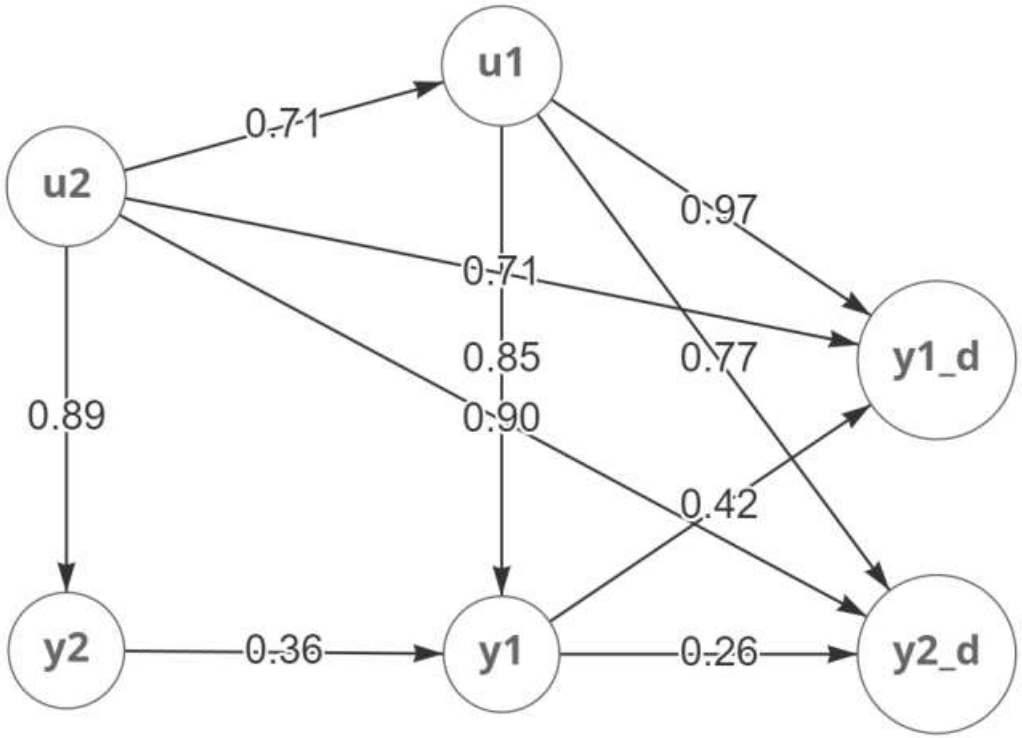
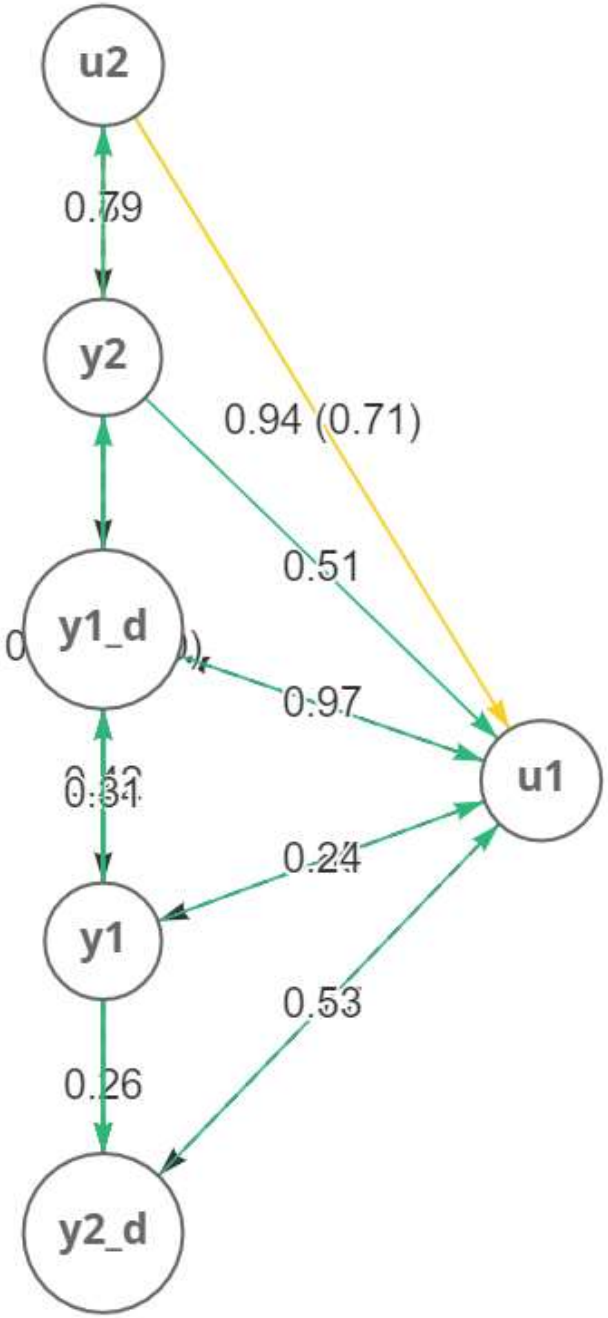
Network Snapshots

Network „0“

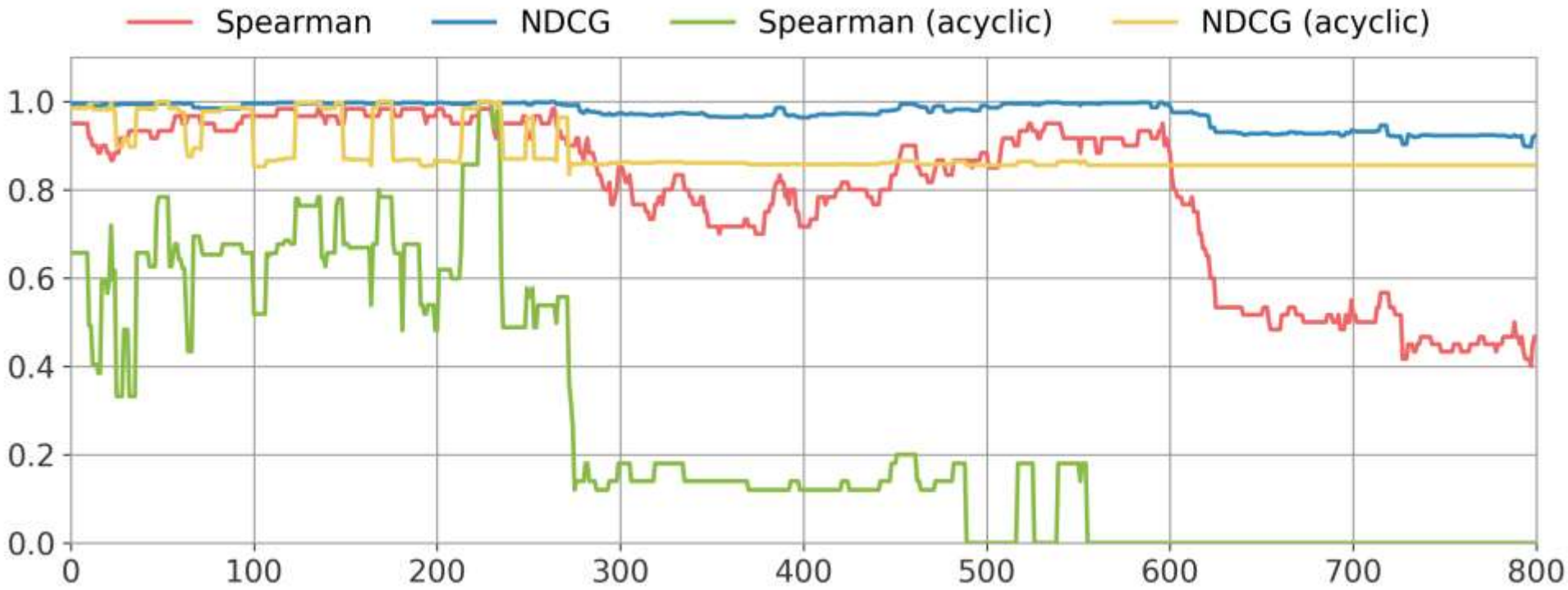


Network „999“



Toy Problem: Communicating Vessels

Detection Qualities

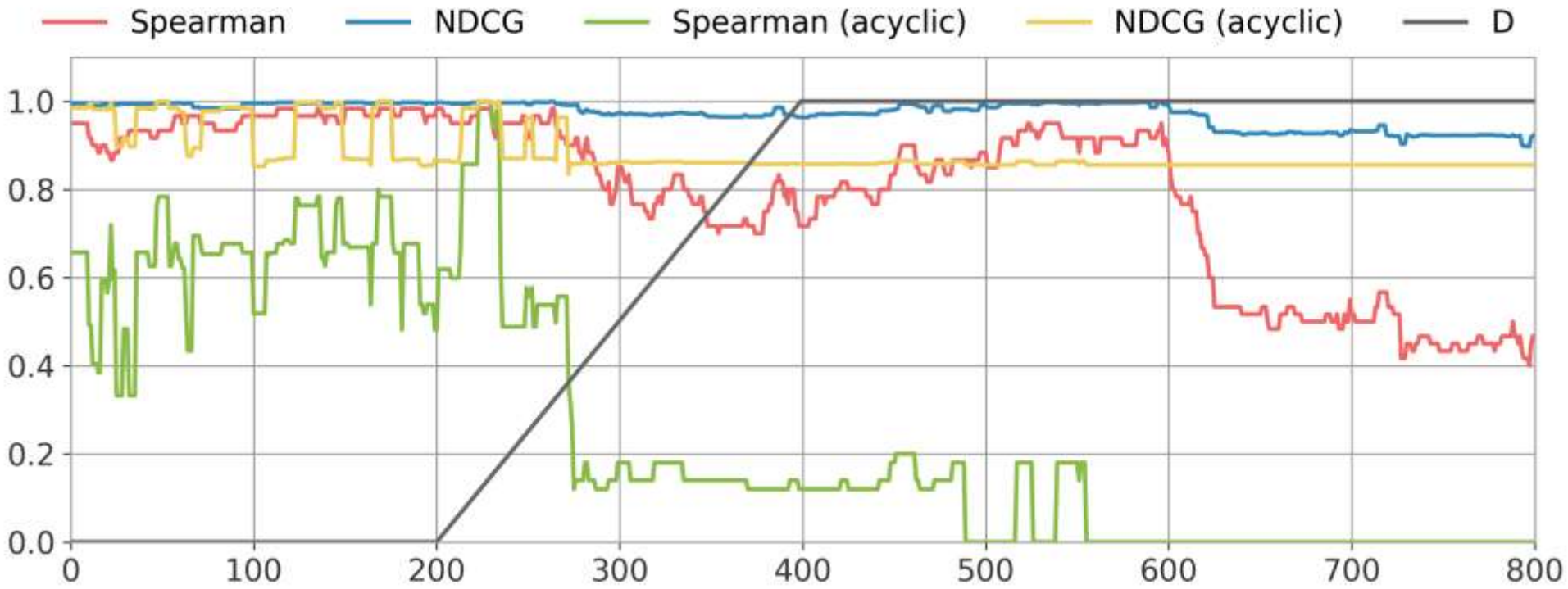


Sample Run:

- Modeling: Symbolic Regression (SR)
- Evaluation: Sliding Window Size = 200

Toy Problem: Communicating Vessels

Detection Qualities vs. Known Degradation



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Toy Problem: Communicating Vessels

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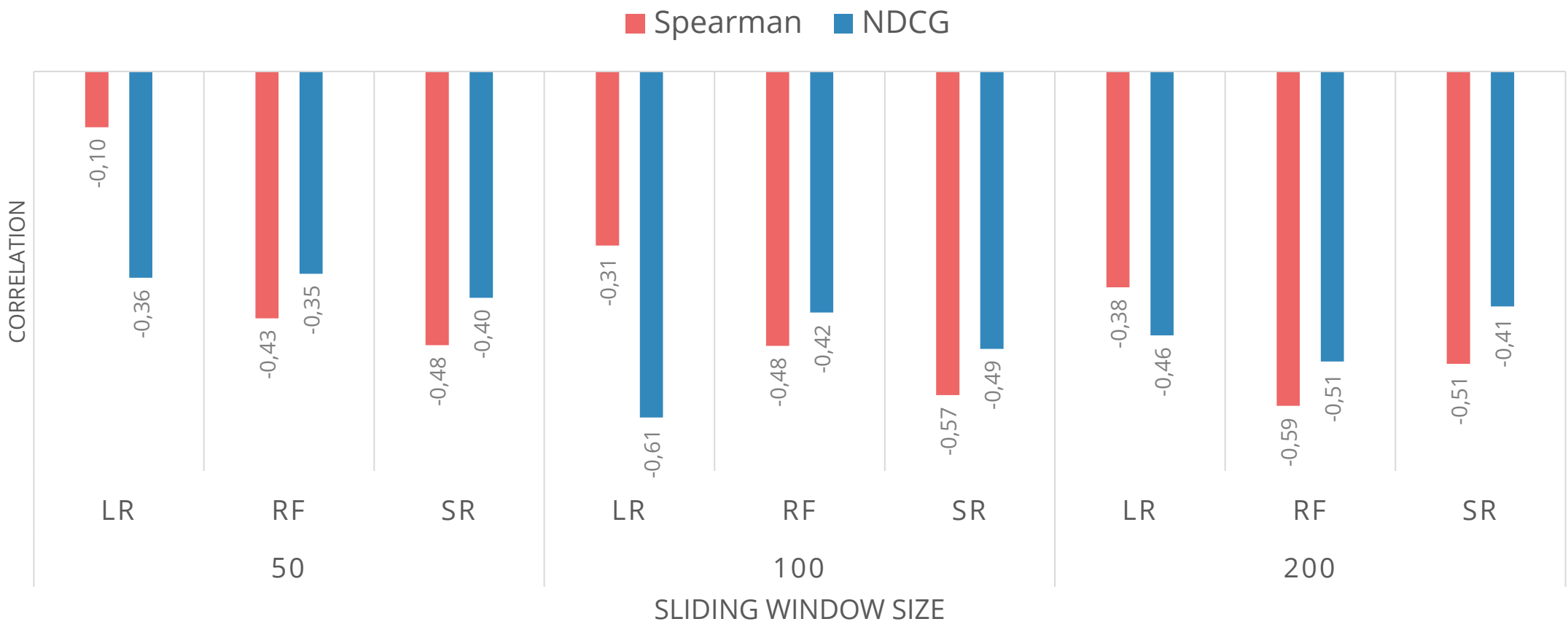
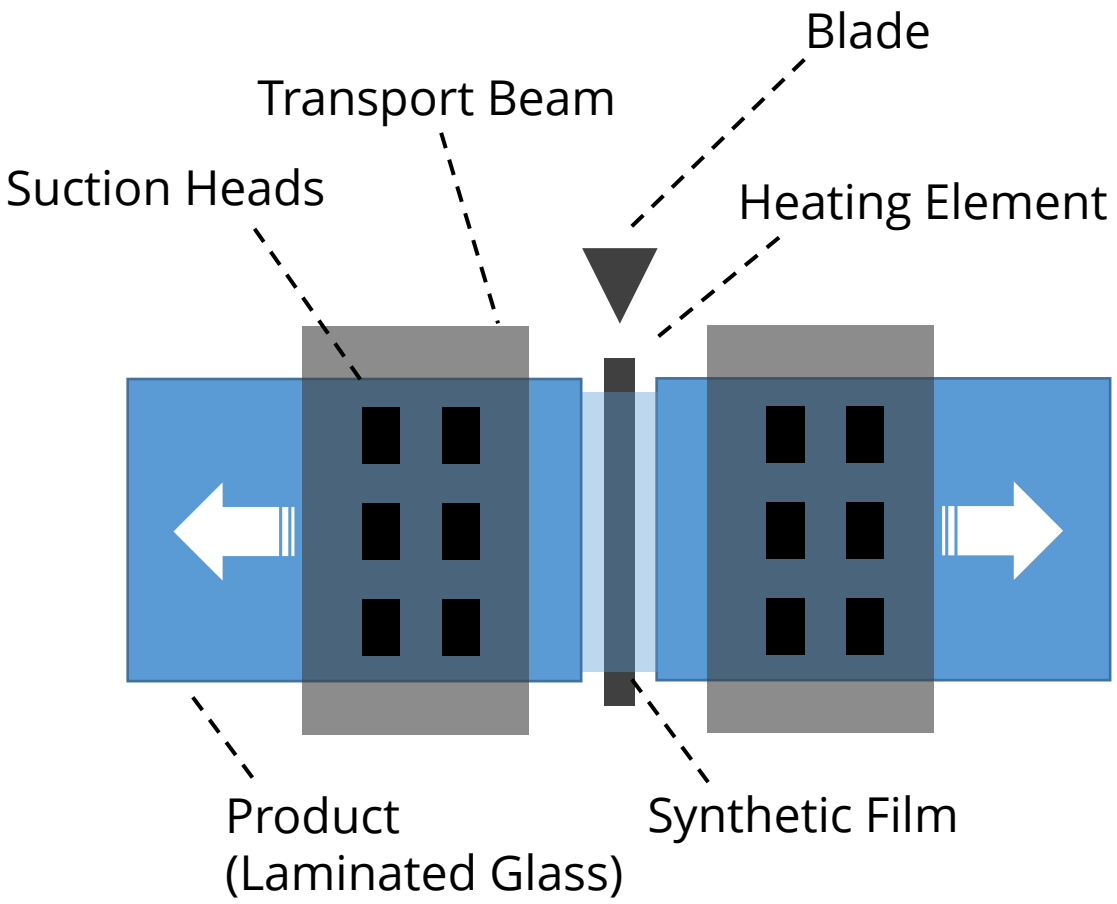


From a recent PdM Pilot Study…

PdM Pilot Study: Cutting Process

Applying Variable Interaction Networks

- Goal: Identify maintenance relevant changes of relationships
- Alternating Targets / Inputs:
  - Process- & recipe parameters
  - Sensor data (time series)
- Potential error causes
  - Heating element,
  - Suction heads,
  - Blade,…



Conclusion and Outlook

- Summary of Contribution
  - Machine learning based algorithm for holistic analysis of system dynamics
  - Algorithm is agnostic to underlying machine learning techniques
  - Implementation for HeuristicLab

- Further Research Questions:
  - Real-world applications
  - Root-cause analysis with variable interaction networks
  - From system dynamics *detection* to *prediction*
  - Open-ended learning

Q & A Concept Drift Detection with Variable Interaction Networks

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