

Causality: Unlocking the power of discovering causal associations in data for monitoring complex industrial processes



Rodrigo Paredes

rparedes@uc.pt

Supervisor: Professor Marco S. Reis ¹

¹. University of Coimbra, Department of Chemical Engineering



MIT Portugal 2023 Annual Conference

MOTIVATION & BACKGROUND

- Standard Statistical Process Monitoring (SPM) methods lose detection and diagnosis performance as we move to high dimensional processes
- Localized faults are easily masked by the normal background process variation
- Even when faults are detected, their diagnosis is very difficult, due to the many potential fault modes and spurious correlations present in data
- Centralized SPM schemes are prone to collapse when variables or blocks of variables are missing
- Causal networks contain rich information that can be used to improve the fault detection sensitivity as well as fault diagnosis

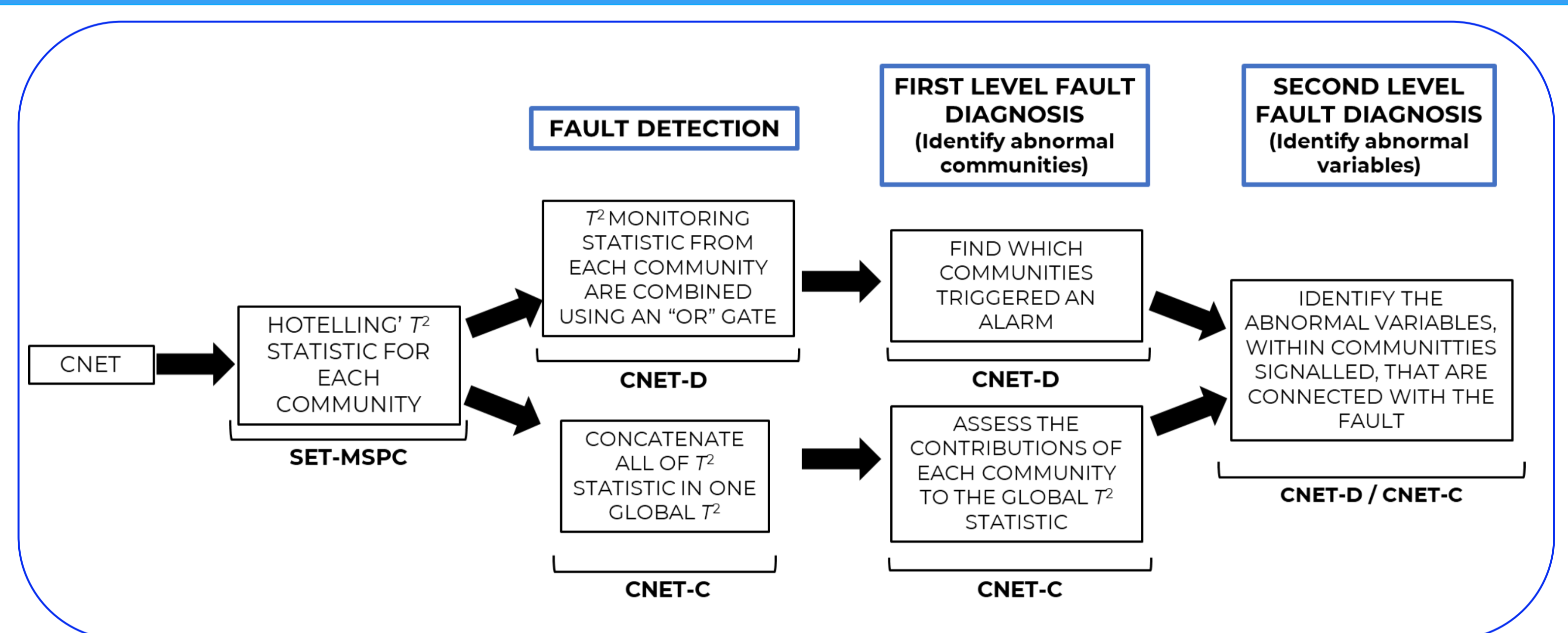
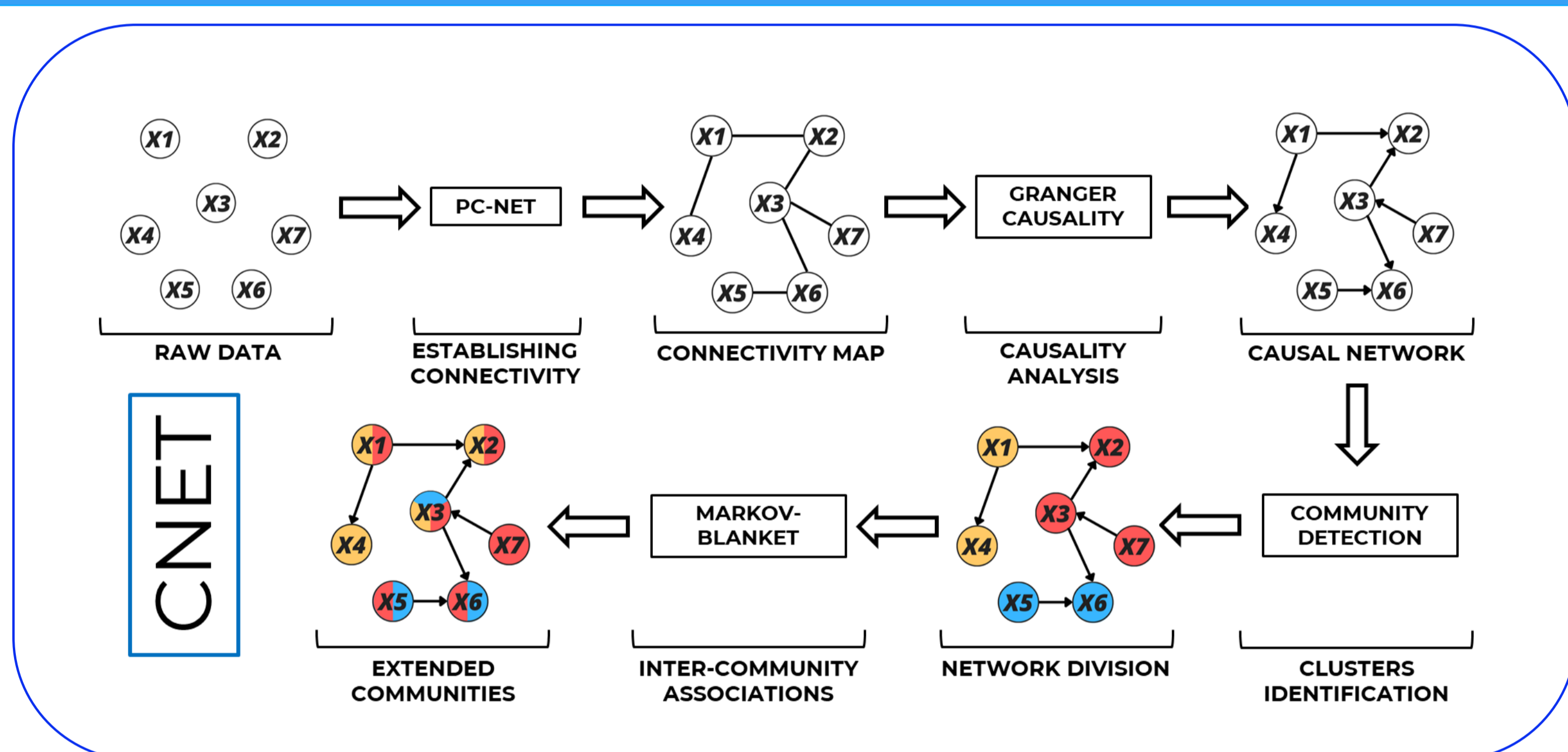
GOALS

- Develop causal-based hierarchical decentralized SPM schemes for Fault Detection and Diagnosis (FDD)
- Demonstrate the advantages of these methodologies for improving FDD performance:
 - Detection
 - Diagnosis

CHALLENGES

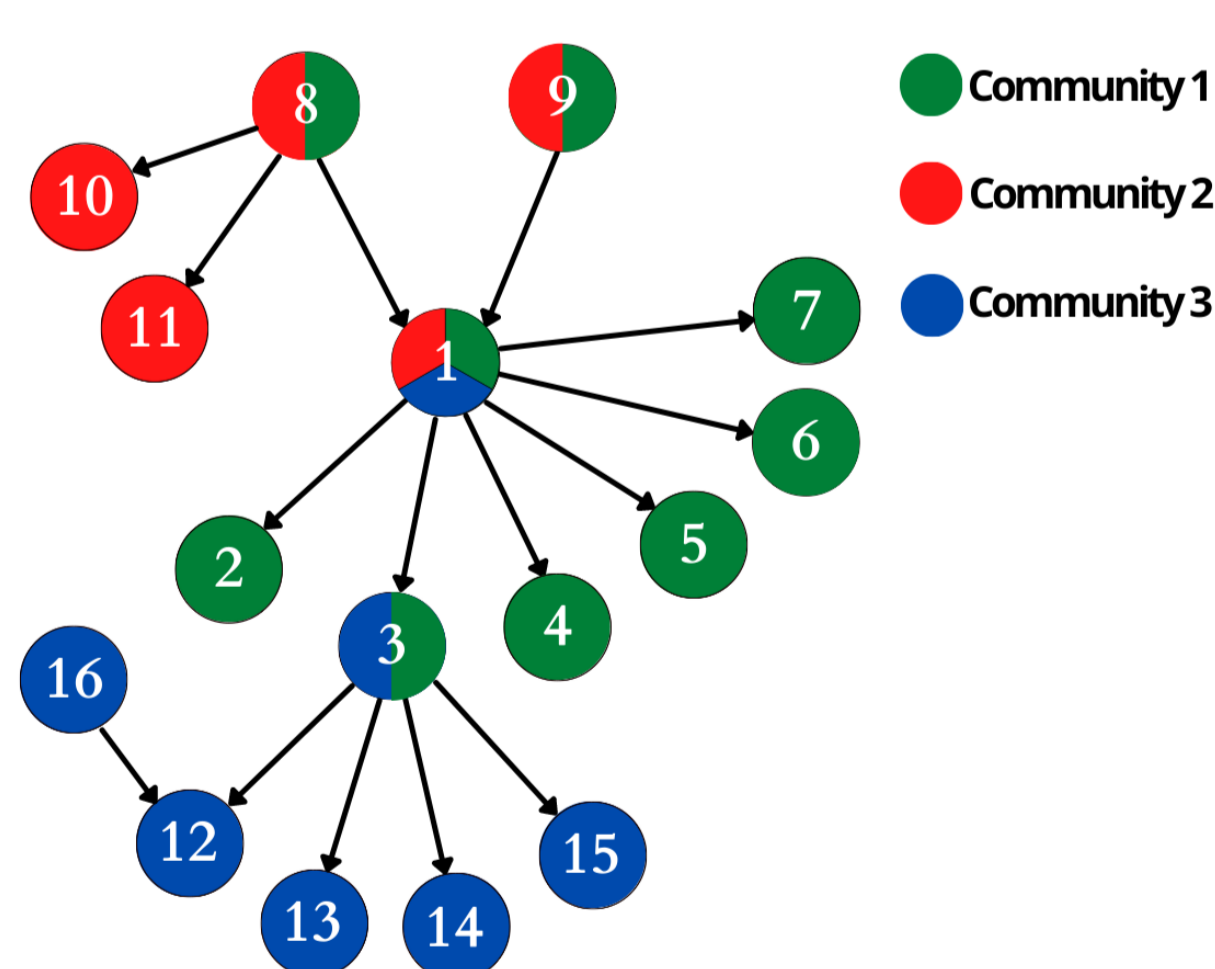
- Estimate the causal network from data
- Identify communities of densely connected nodes
- Incorporate causal information in SPM methodologies (micro- and macro-causality)

PROPOSED METHODOLOGIES: CNET-C & CNET-D



RESULTS

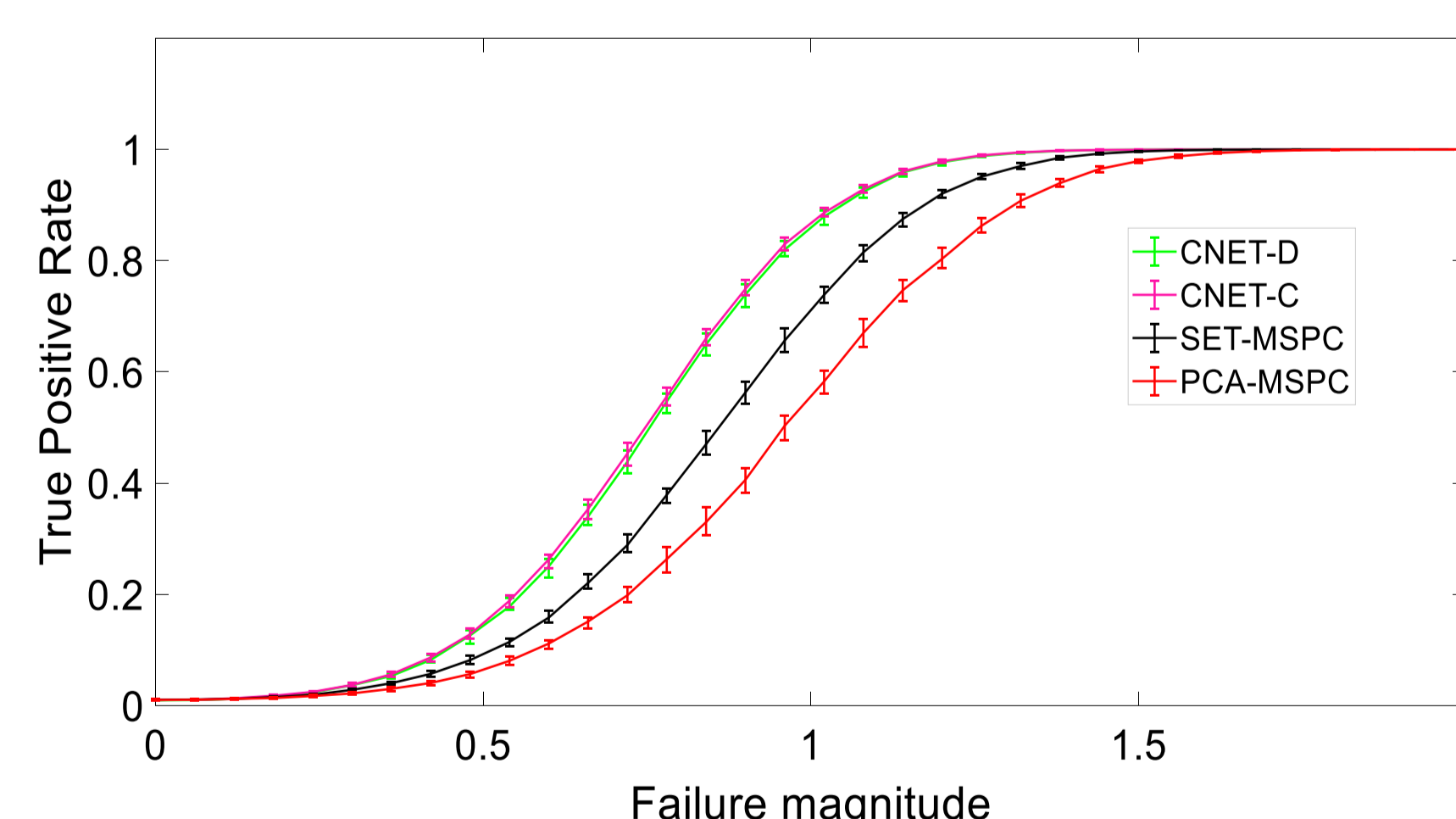
Outcome of CNET for an artificial causal network composed with 16 variables



CNET

TPR for **process fault in variable X₁** using:

- 1 CNET-D & CNET-C
- 2 A correlation-based method, PCA-MSPC
- 3 A causal-based method, SET-MSPC

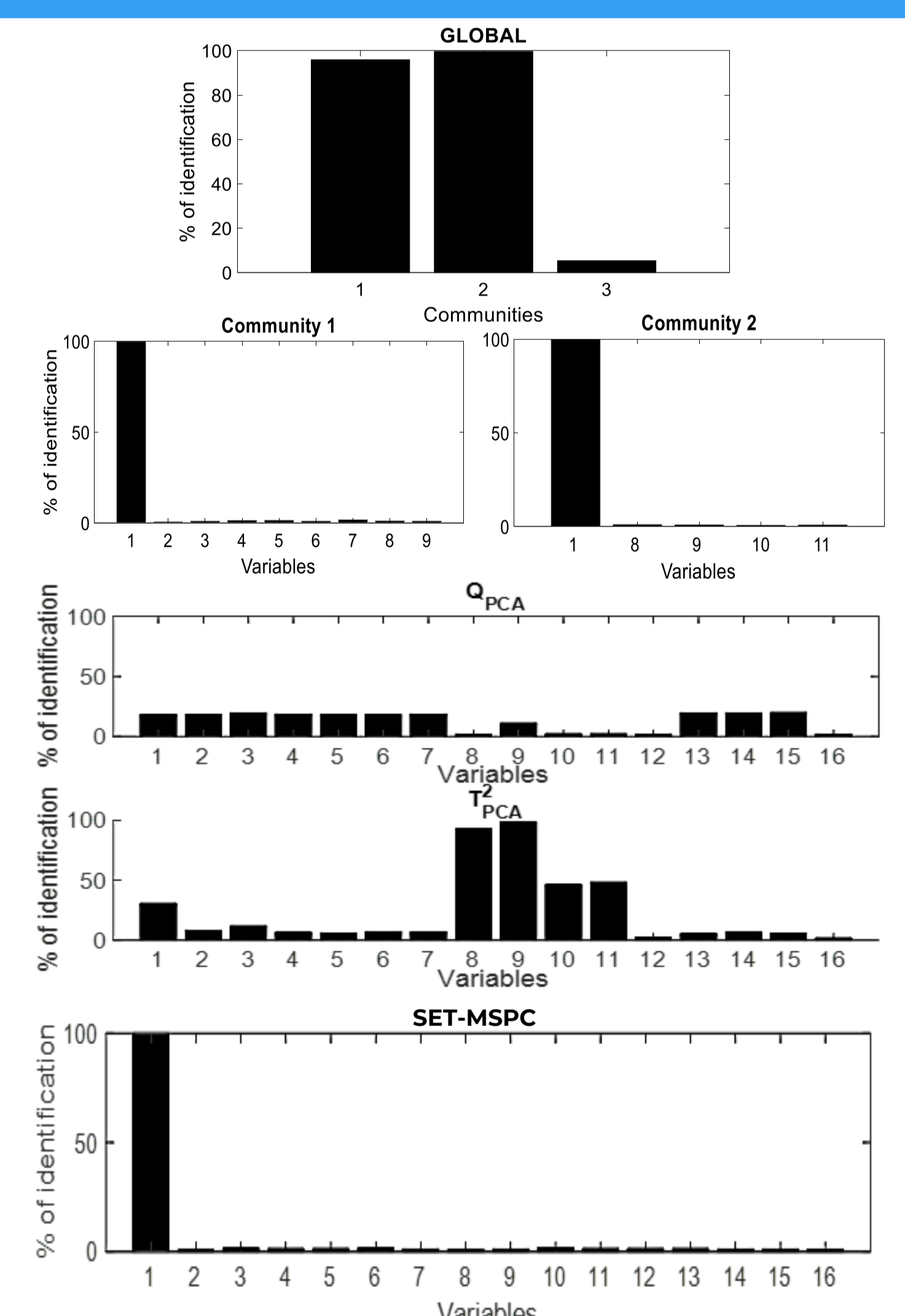


FAULT DETECTION

1

2

3



FAULT DIAGNOSIS

CONCLUSIONS

- More data improves reconstruction accuracy
- Decomposing the causal network into functional modules enhances detection sensitivity
- CNET-C and CNET-D consistently outperform benchmark methods in fault detection
- CNET-C is effective for process and correlation faults, while CNET-D excels in sensor faults
- Markov-blankets enable including inter-community associations (macro-causality) in models
- Proposed methods ensure unambiguous diagnosis, with <2% misidentification of other variables

REFERENCES

- ❖ Rato, T.J., Reis, M.S., 2014. Sensitivity enhancing transformations for monitoring the process correlation structure. *J. Process Control* 24, 905–915.
- ❖ Ge, Z., Song, Z., Gao, F., 2013. Review of Recent Research on Data-Based Process Monitoring. *Ind. Eng. Chem. Res.* 52, 3543–3562.
- ❖ Reis, M., Gins, C., 2017. Industrial Process Monitoring in the Big Data/Industry 4.0 Era: from Detection, to Diagnosis, to Prognosis. *Processes* 5, 35.

Funded by:

