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Graph Anomaly Detection with GNNs: A Case Study on Predictive Maintenance for ENI's Industrial Machinery

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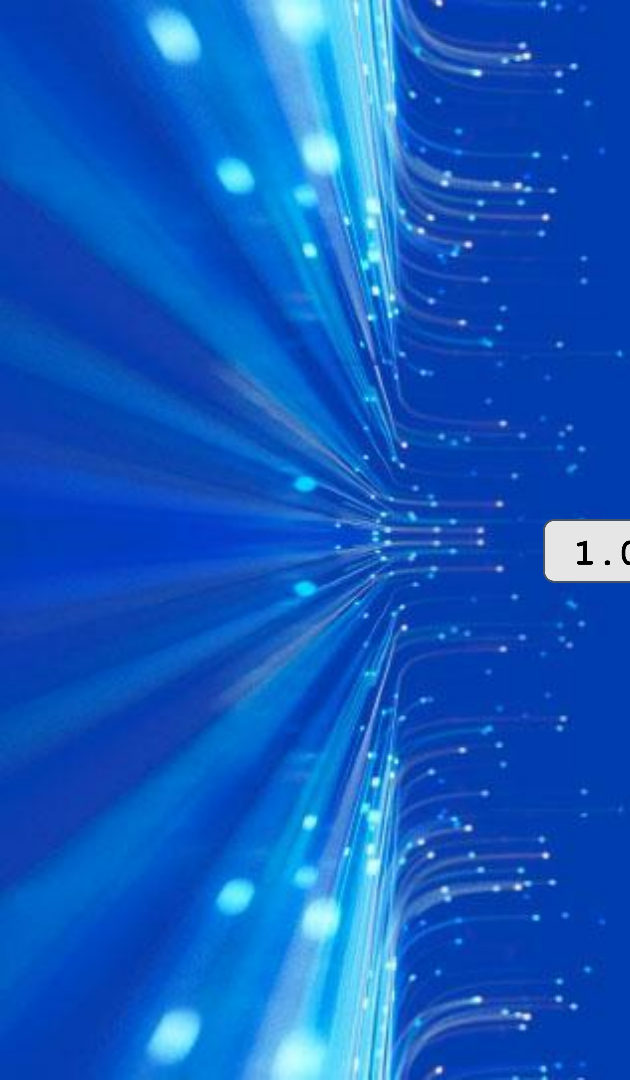

1.0

RESEARCH FRAMEWORK

Research Framework

In mission-critical industries, continuous operation exposes equipment to wear that can escalate into costly failures and downtimes.

Raw data from IoT sensors enables real-time monitoring and predictive maintenance (PdM) of systems.

↓

The goal is to perform maintenance when the maintenance activity is most **cost-effective** and **before the system loses performance**, going below an acceptable threshold.

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Innovation Grant:

"Harnessing the Power of Artificial Intelligence for Predictive Maintenance of Industrial Plants"

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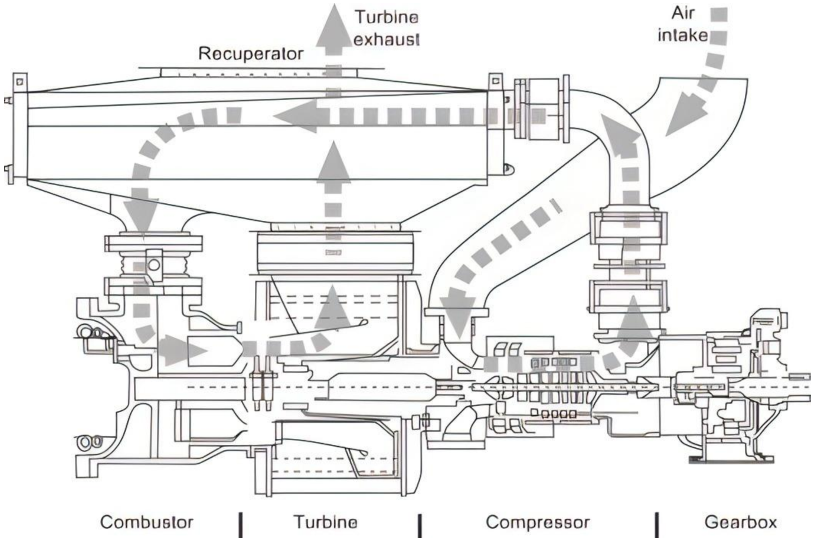
2.0

OUR APPROACH

Dataset

We tested our model on signals from industrial rotating machines operating at the ENI COVA plant [1]. For instance, we analyzed multivariate time-series data from a turbine generator, dedicated to supply the entire plant.
The series includes measurements from 55 sensors collected over a 390 days period.

Measurement Type	Object of measurement
Turbine Operating Conditions	Turbine speed, Rotor speed
Temperatures	Fuel, Lube Oil, Bearings, Thermocouples, Drains, Enclosure
Pressures	Fuel, Lube Oil
Vibration Levels	Turbine Bearings, Gearbox, Generator
Electrical	Generator Amperage, Voltage, Frequency, Output and Reactive Power



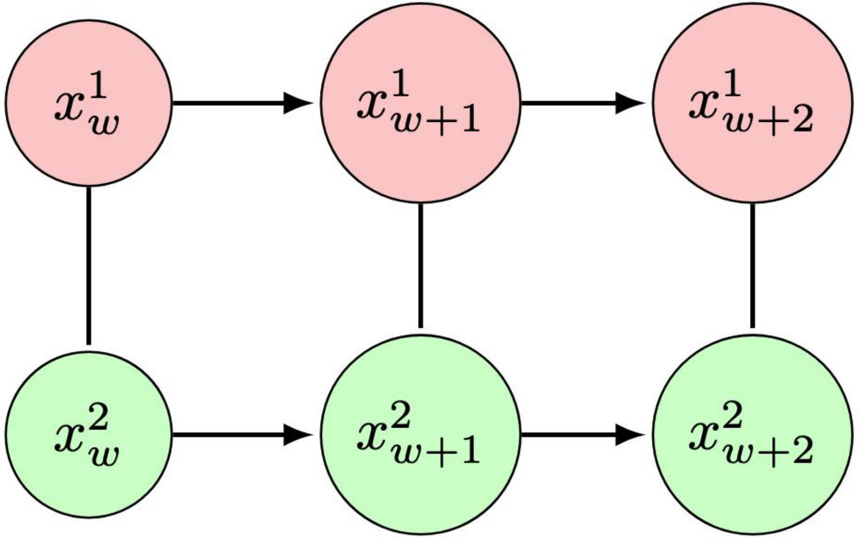
From Time-Series to Graphs

We followed a correlation network approach yielding to a single-layer of observations-based nodes [2].

Cross-Correlations →

Autocorrelations ↓

Time	sensor1	sensor2
t_1	x_1^1	x_1^2
t_2	x_2^1	x_2^2
t_3	x_3^1	x_3^2
	...	...
t_w	x_w^1	x_w^2
t_{w+1}	x_{w+1}^1	x_{w+1}^2
t_{w+2}	x_{w+2}^1	x_{w+2}^2



From Time-Series to Graphs

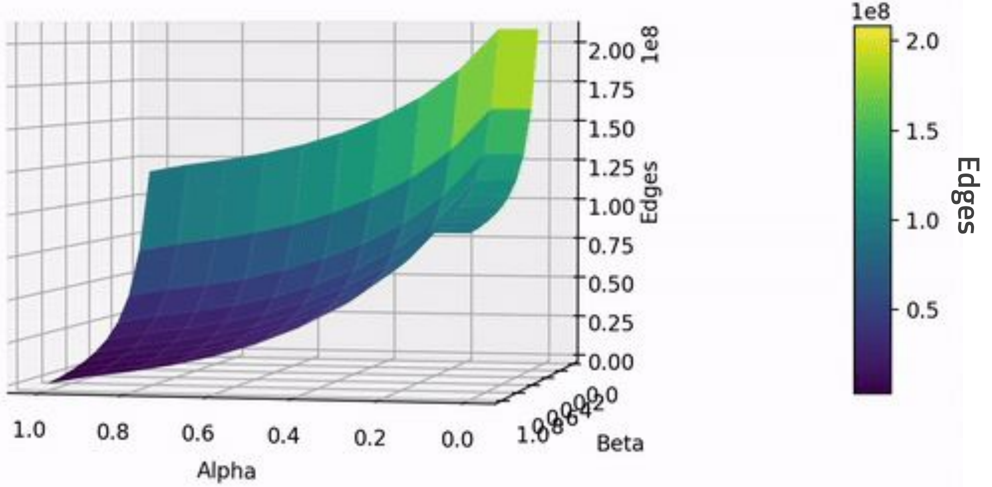
Two nodes are connected if the correlation between the signals in the last ***w*** timestamps is higher than **Alpha**. Similarly, two nodes associated with the same signal are connected if the autocorrelation between those timestamps is higher than **Beta**.

Alpha = 0.4, Beta = 0.3,
w = 100

Frequency: 5 min
Variables: 55
Nodes: 6.186.620
Edges: 150.476.153

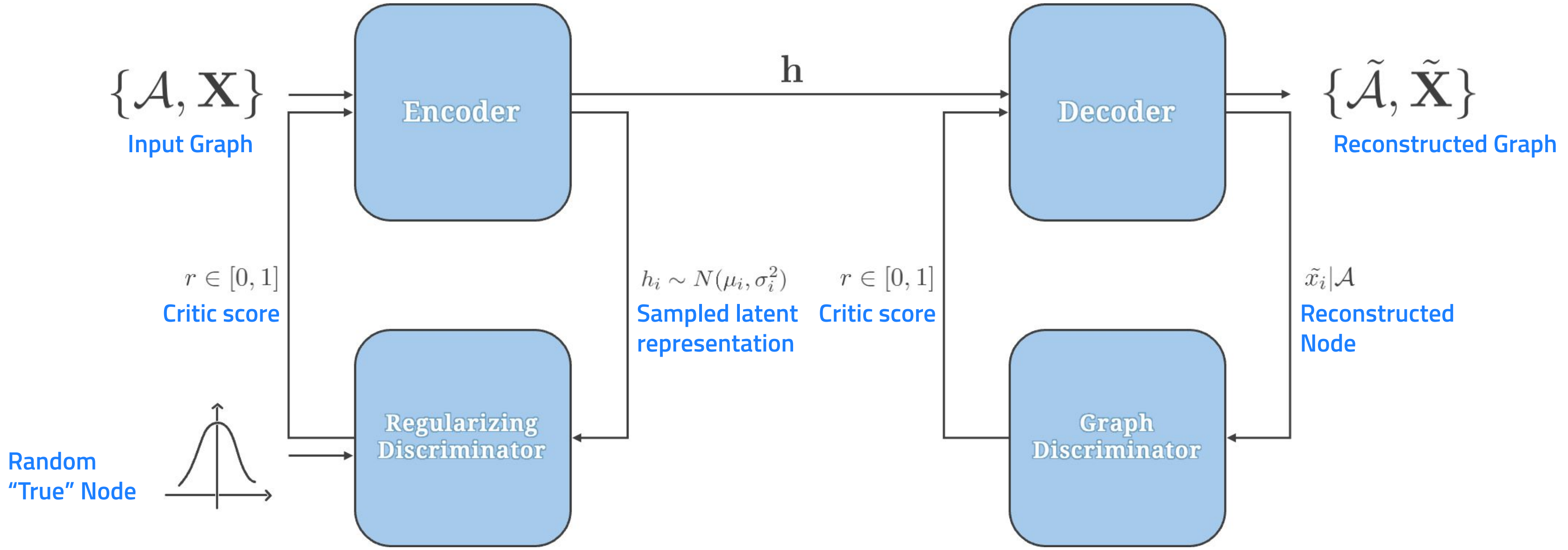
↓

<1hr on LEONARDO DCGP [3]



Our Model

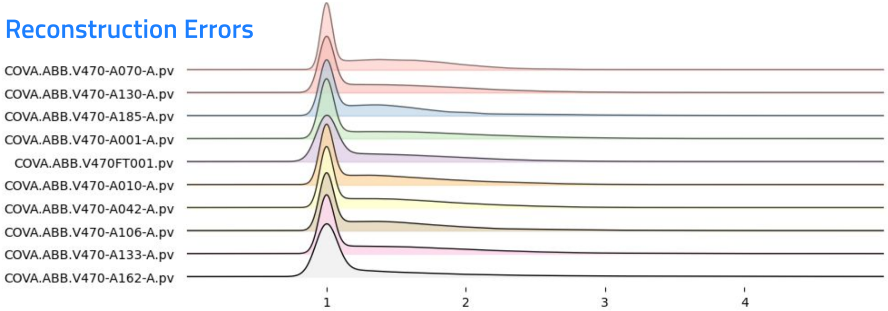
We can think of this model as two interconnected Generative Adversarial Networks (GANs), where the Autoencoder works as a double generator.

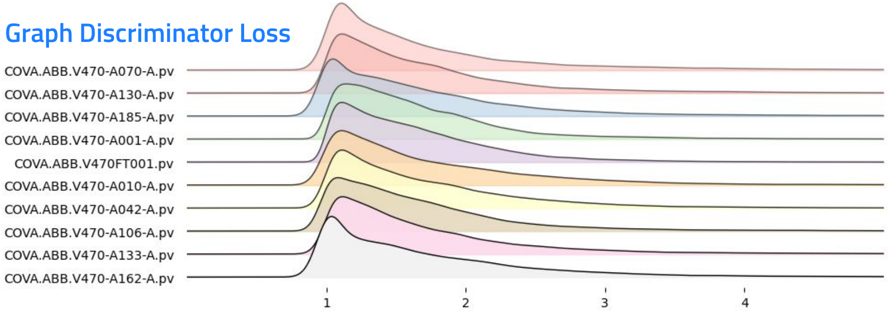


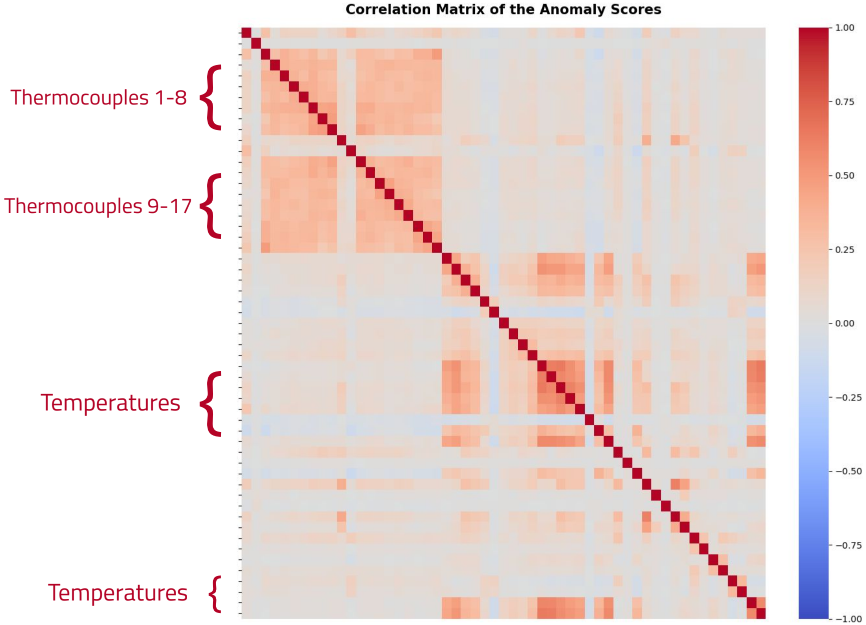
3.0 RESULTS

Anomaly Scores

Our model generates both a critic score and a reconstructed attribute for each node in the input graph, i.e. for each (time, signal) pair. This allows for a fine-grained examination of the model's predictions.

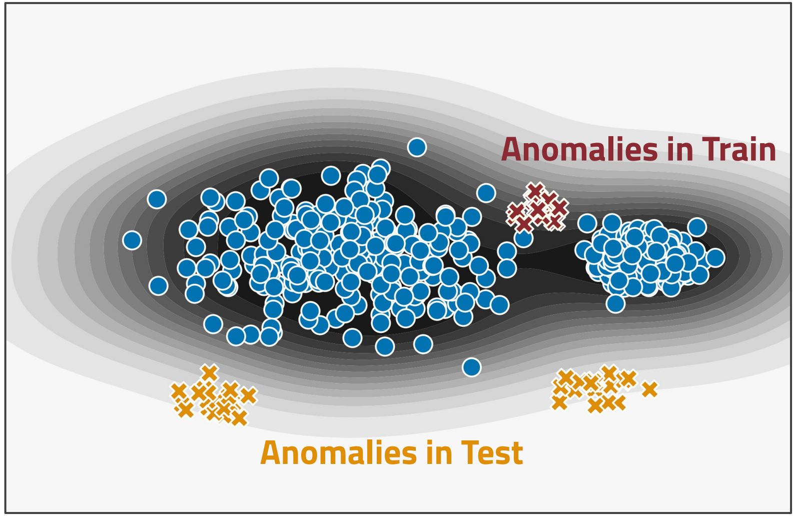


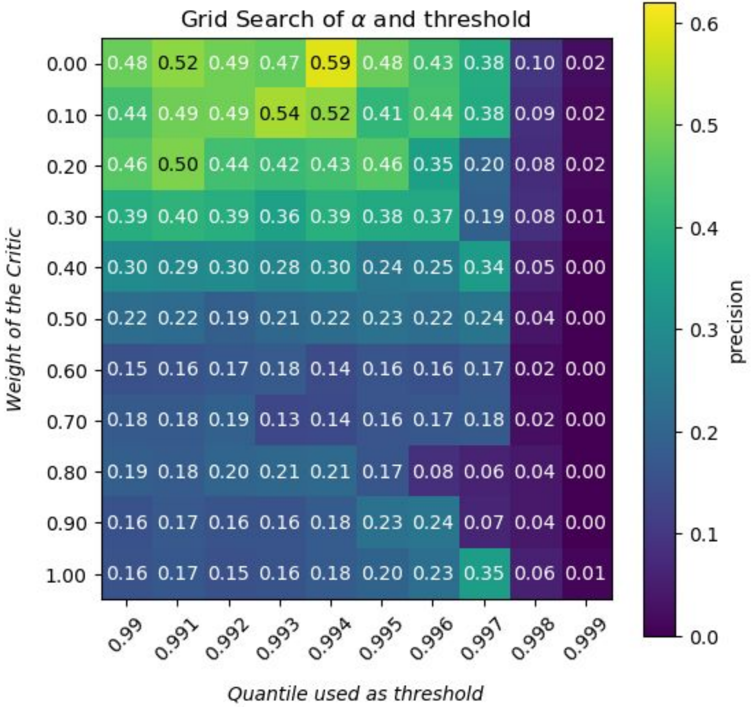




2 Phase Semi-Supervised Method

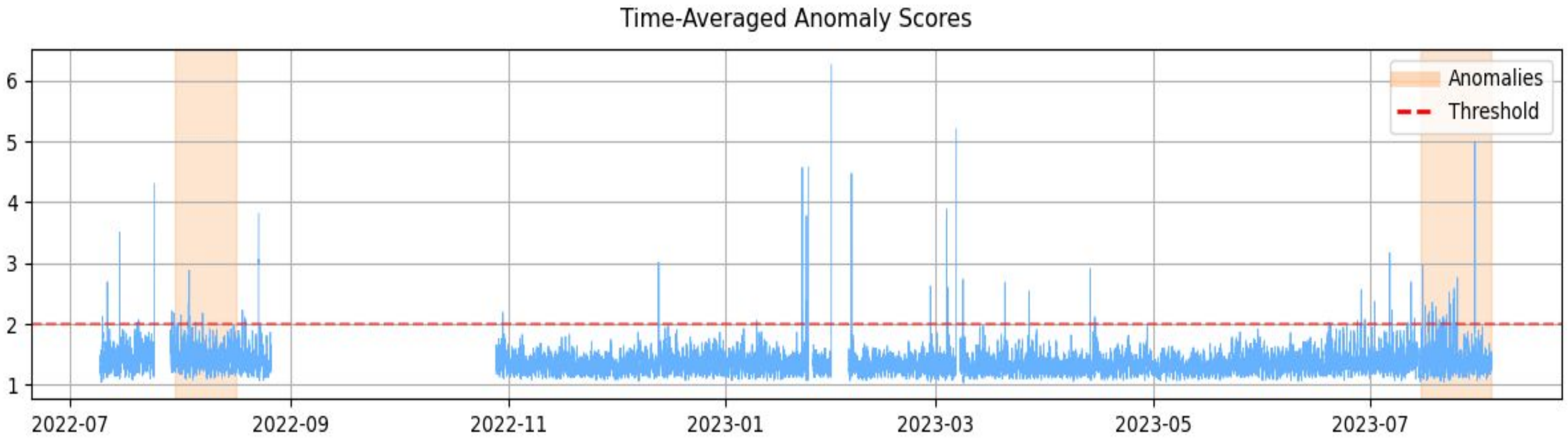
By removing known anomalies in training, the model learns the normal data representation.
A decision threshold is tuned to correctly identify all anomalies possibility without misclassifying normal data.





Anomaly Detection

A threshold is required to do the decision: if the score for a point is greater than the threshold, an alert should be triggered. In this way, anomaly detection is similar to an imbalanced classification problem and well-known evaluation metrics can be used.



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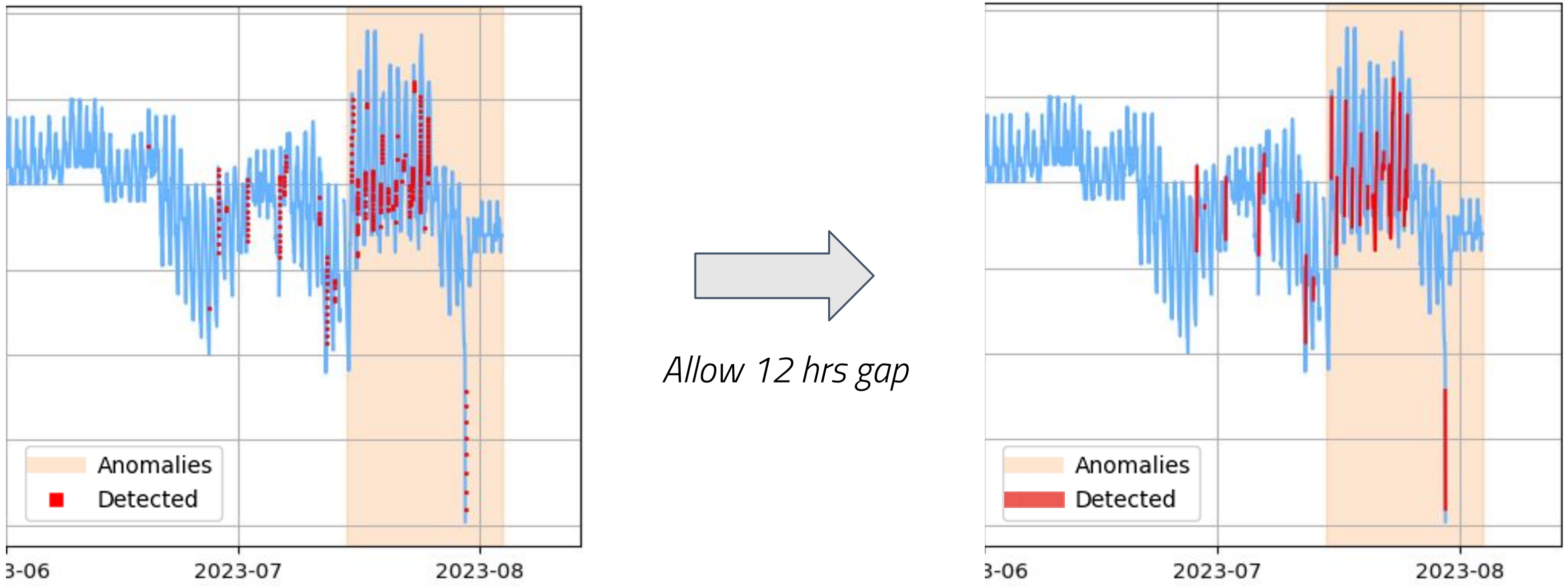
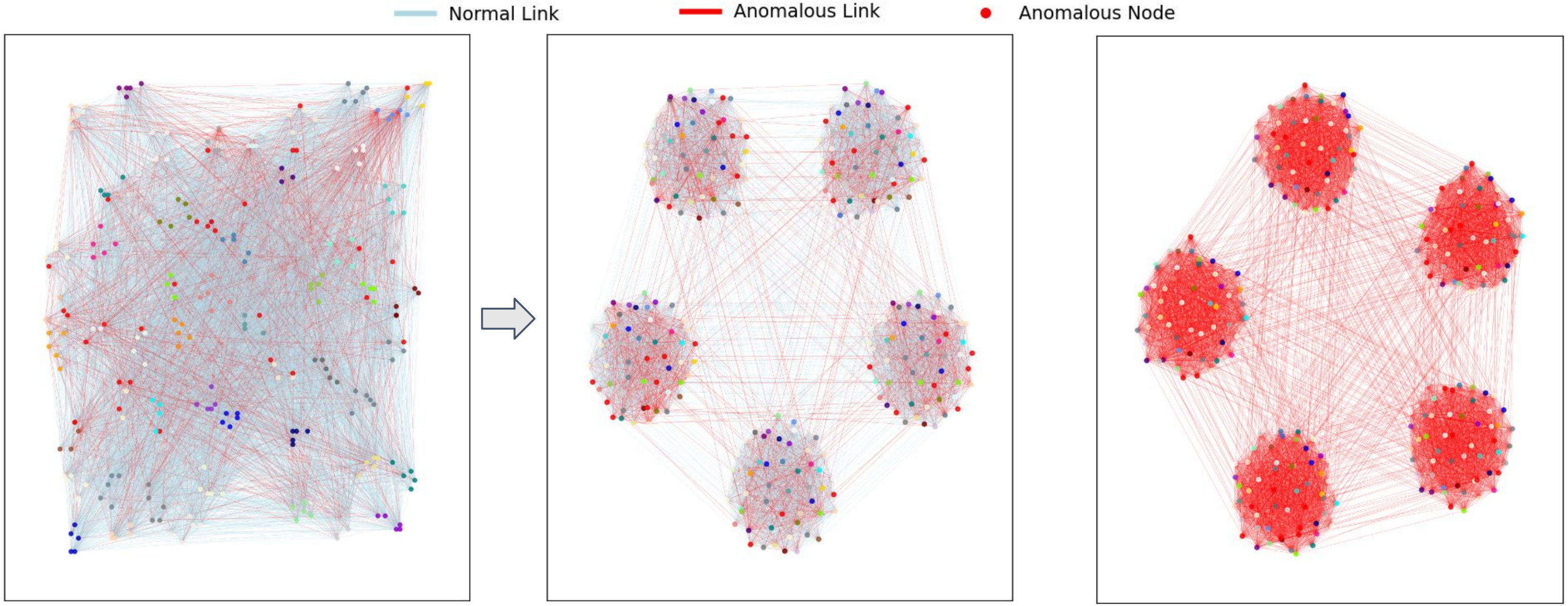
Anomaly Detection

In real applications, the human operators generally do not care about these point-wise metrics. In practice, anomalous observations usually occur continuously to form contiguous anomaly segments. Thus, it is acceptable for an algorithm to trigger an alert for any point in a contiguous anomaly segment, if the delay is not too long [4].



Model Interpretation with Graphs

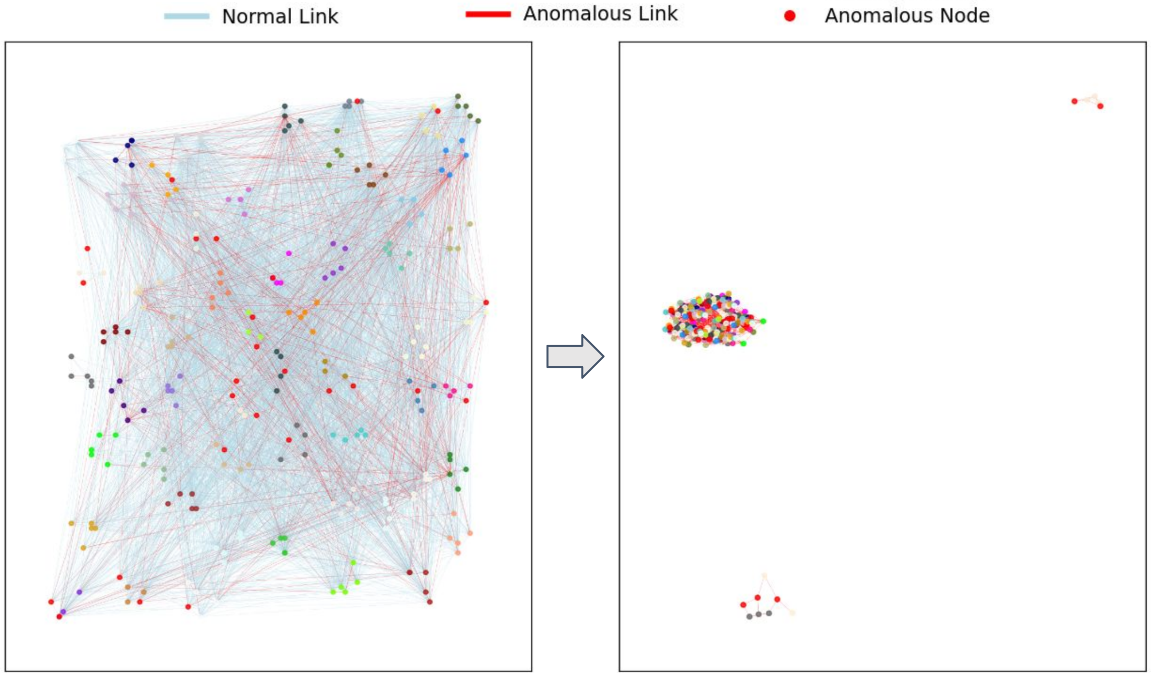


A shutdown subgraph

An anomalous connected subgraph

An anomalous connected subgraph, nearly all nodes and links show high levels of abnormality

Model Interpretation with Graphs



A subgraph from anomalous interval

A unique anomalous connected subgraph

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Thanks!

Any questions or comments?

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References

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2. Yang, Y. and Yang, H. (2008). Complex network-based time series analysis. Physica A: Statistical Mechanics and its Applications, 387(5–6):1381–1386.
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4. Su, Y., Zhao, Y., Niu, C., Liu, R., Sun, W., & Pei, D. (2019). Robust Anomaly Detection for Multivariate Time Series through Stochastic Recurrent Neural Network. Proceedings of the 25th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining. https://doi.org/10.1145/3292500.3330672