High-Performance Unsupervised Anomaly Detection for Cyber-Physical System Networks

Peter Schneider, Konstantin Böttinger, October 19, 2018 / CPS-SPC

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Nationales Referenzprojekt
IT-Sicherheit in Industrie 4.0

Anomaly Detection for CPS Networks

Intro

Who	*Peter Schneider*, Konstantin Böttinger
What	Anomaly Detection
When	Online Detection
Where	Cyber-Physical System Networks
Why	High-Performance, Unsupervised
How	Stacked Denoising Autoencoders
For what	Detection in proprietary and/or binary protocols

Anomaly Detection for CPS Networks

Motivation

- Rising number of attacks on cyber-physical systems (CPS)
- 100%-secure systems are impossible
- Network-based Anomaly Detection widely suggested as solution

Anomaly Detection for CPS Networks

The Problem

- Detection systems for business IT already available
- Adaptation of systems to CPS domain still ongoing
- Including domain-specific knowledge should increase detection capabilities

Anomaly Detection for CPS Networks

What happens now

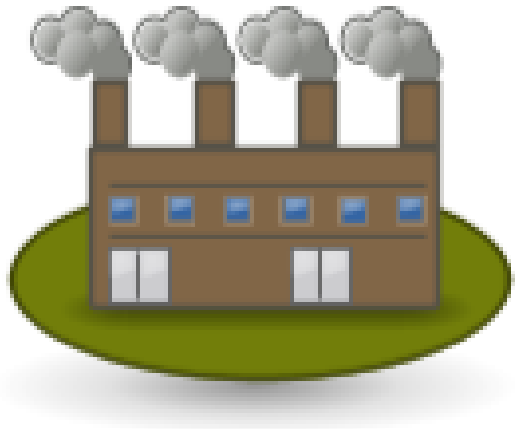

Figure: Insecure manufacturing system.

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What happens now

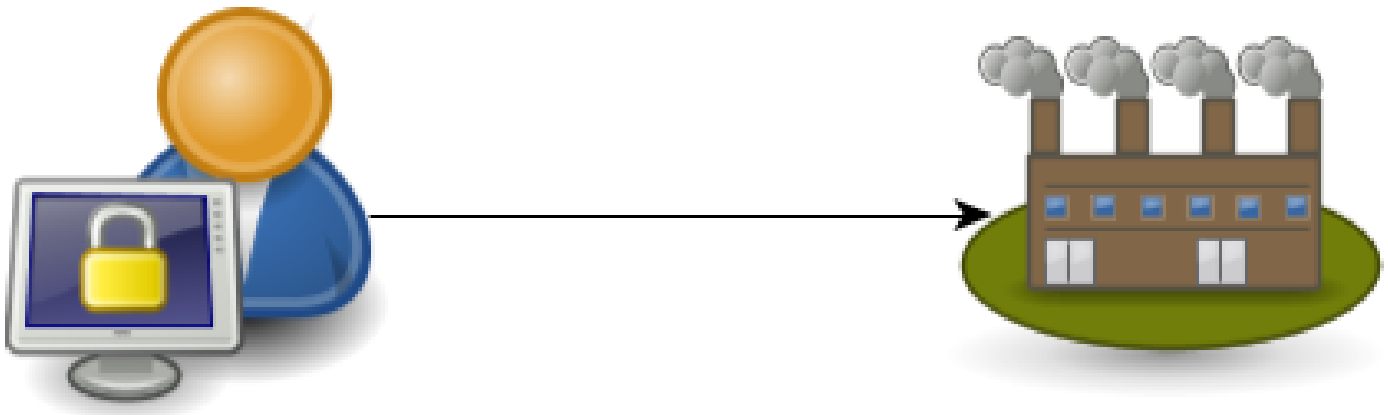

Figure: Secure manufacturing system.

Anomaly Detection for CPS Networks

Challenges

- slow updates
- long product lifetime
- once protected environments
- high damage potential
- specialized attacks
- binary/proprietary protocols

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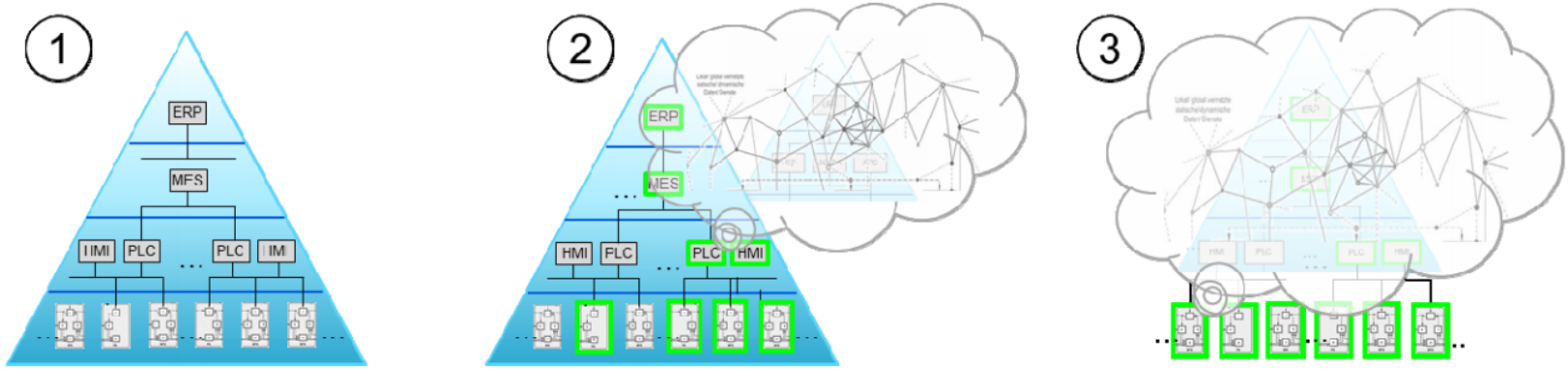

Figure: VDI, Cyber-Physical Systems: Chancen und Nutzen aus Sicht der Automation

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Anomaly Detection for CPS Networks

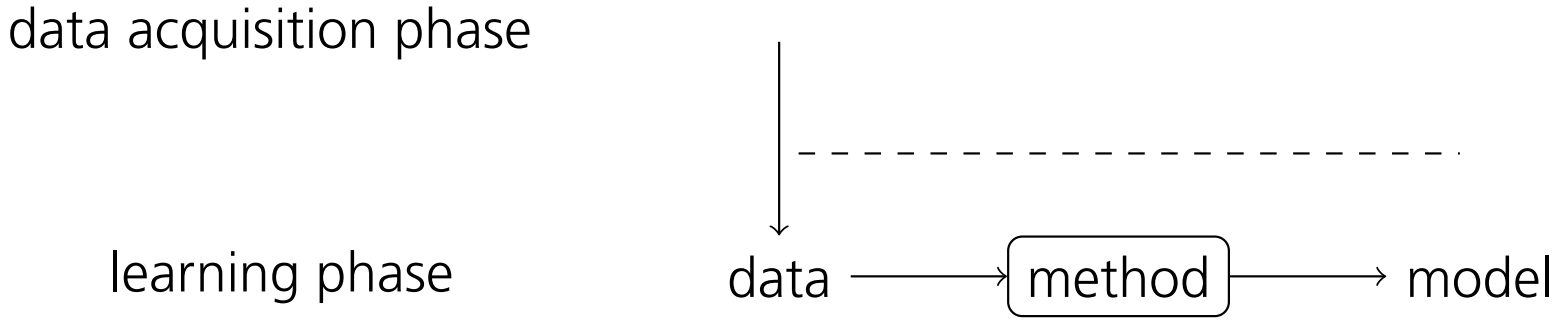
How it is usually done

data acquisition phase

data

Anomaly Detection for CPS Networks

How it is usually done



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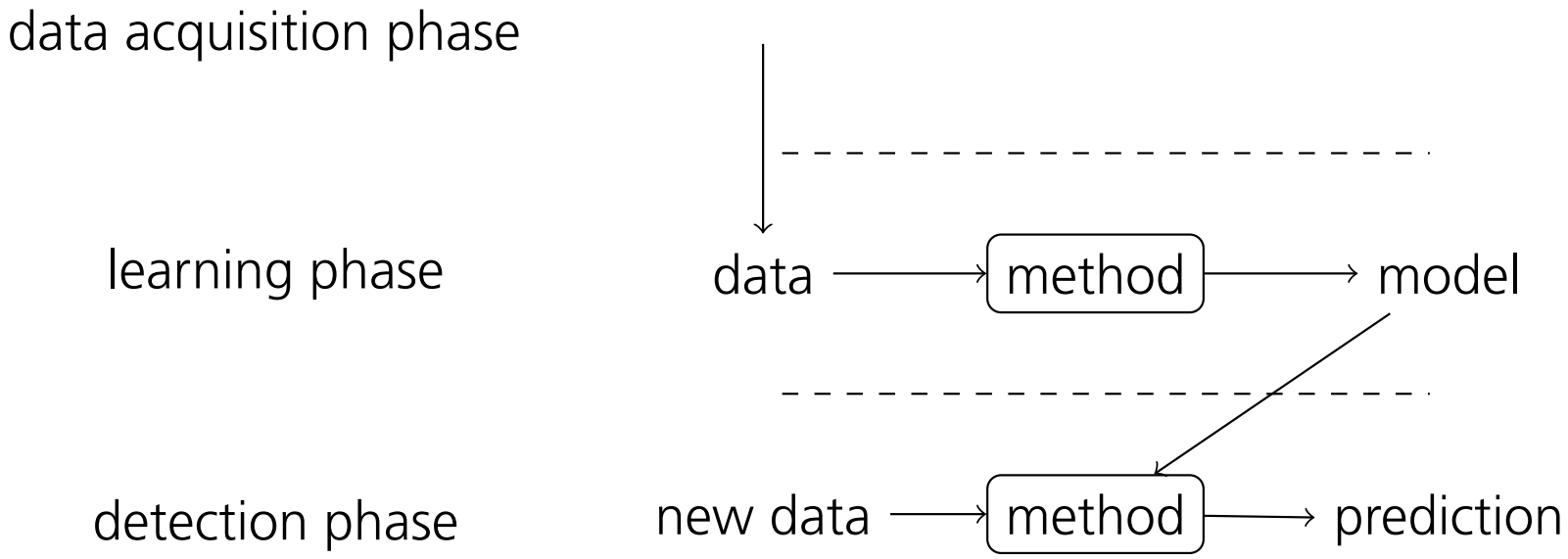

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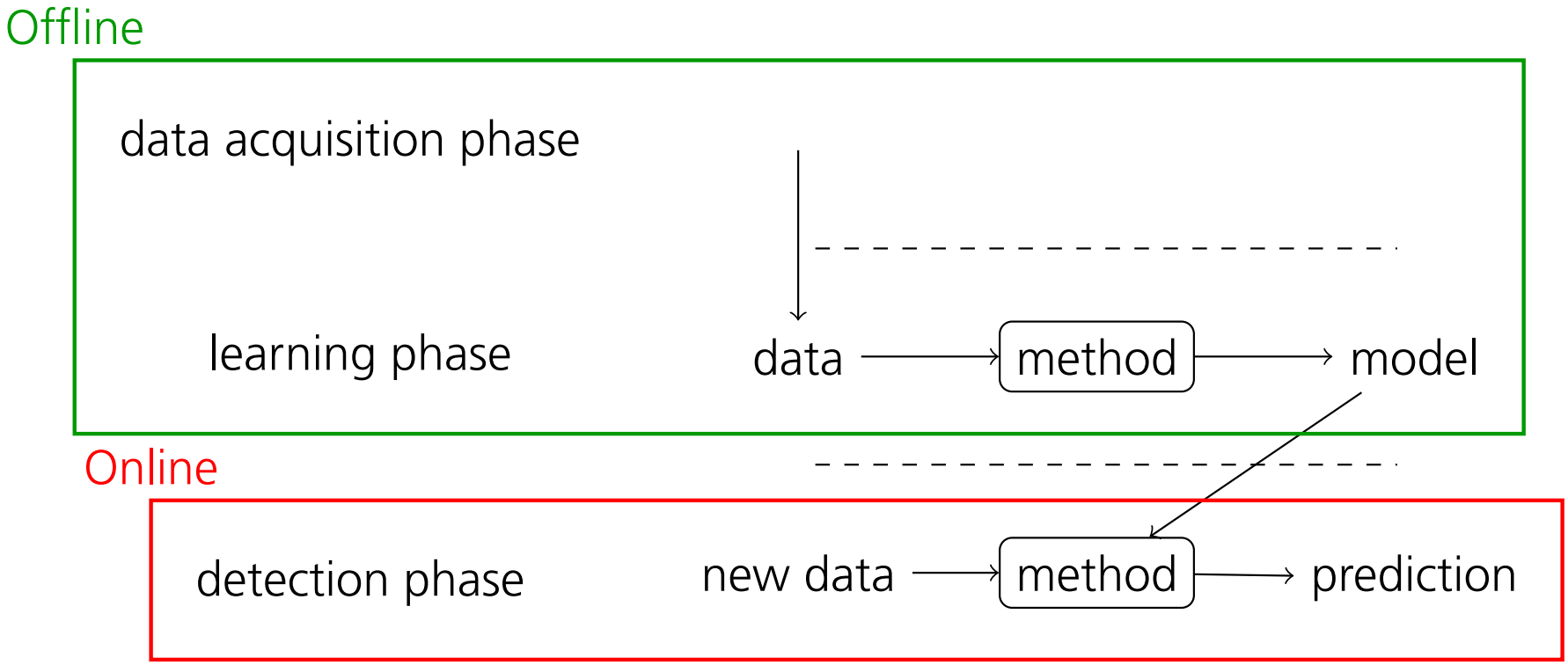

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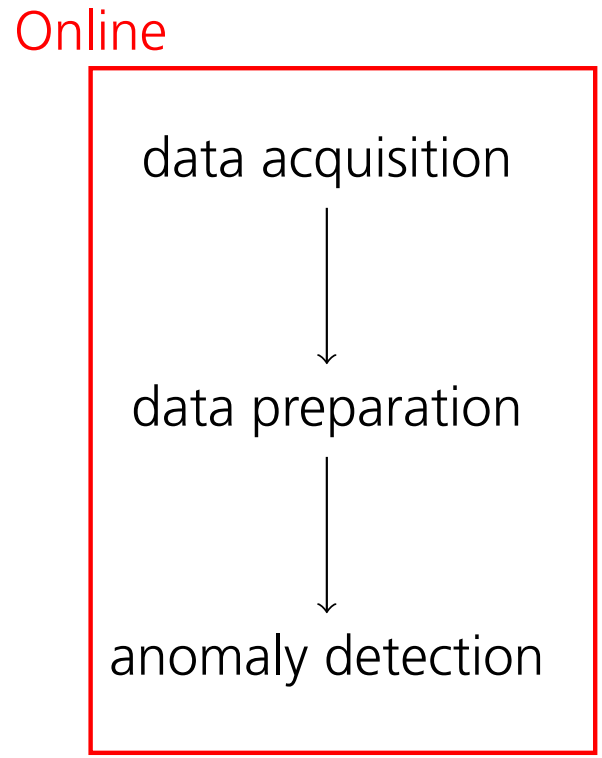
How it (not) works



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Performance

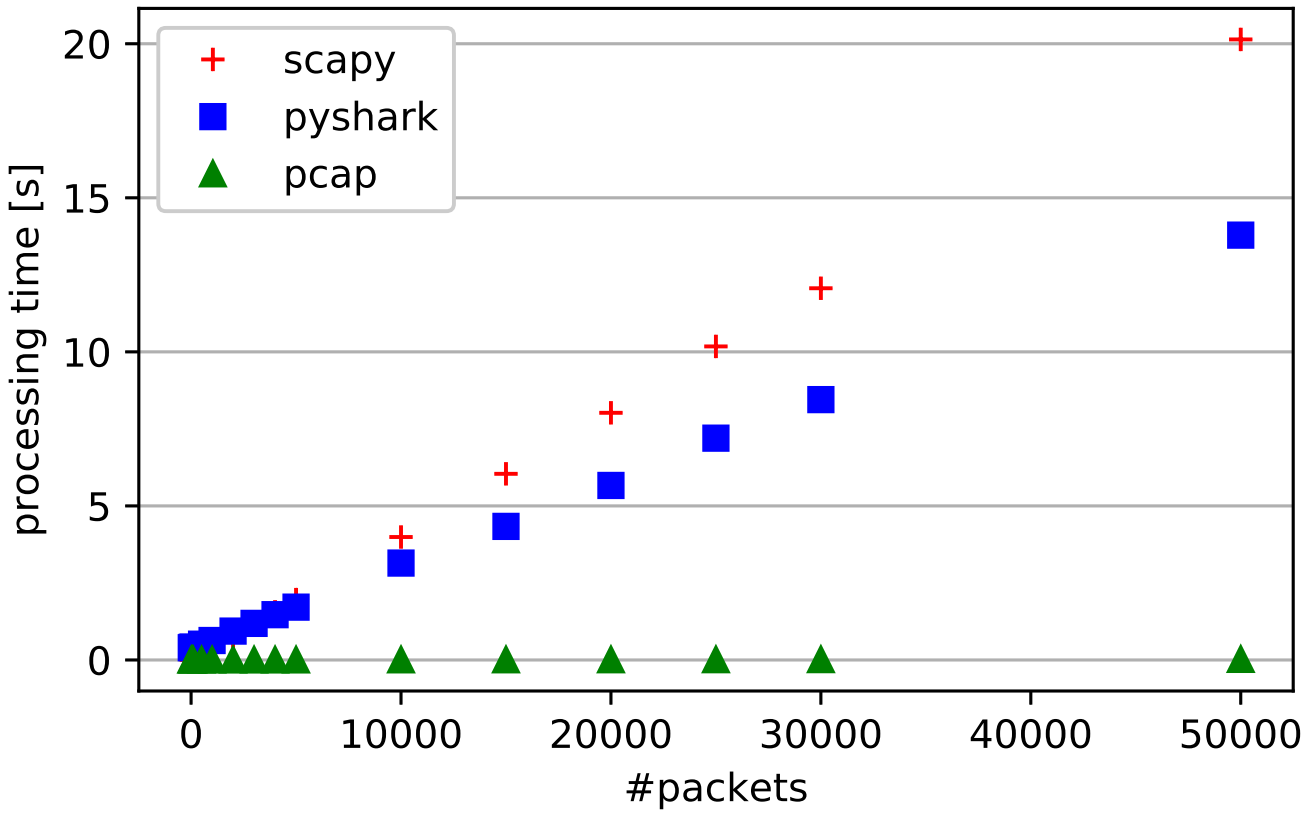

Figure: Performance comparison using different data aggregation strategies.

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Performance

# packets	scapy	pyshark	pcap
1000	0.38*s*	0.63*s*	$< 0.01s$
3000	1.17*s*	1.19*s*	$< 0.01s$
10000	3.99*s*	3.15*s*	$< 0.01s$
50000	20.14*s*	13.79*s*	0.02*s*

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Assumptions bandwidth: $100 Mbit/s$, average packet length: $100 bytes$

Result up to **131072** network packets per second

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Observations

- packet parsing infeasible for larger CPS networks
- classic ML feature extraction not possible

We need a faster solution for **feature extraction** and **anomaly detection**!

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Pipeline

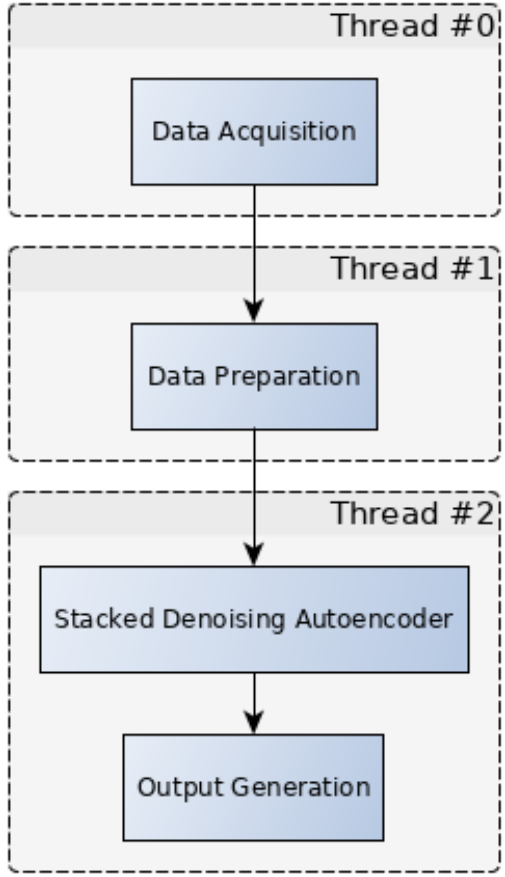

Figure: High-Performance Pipeline

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Pipeline

data acquisition real-time capturing

data preparation length cut-off or padding

anomaly detection stacked denoising autoencoders

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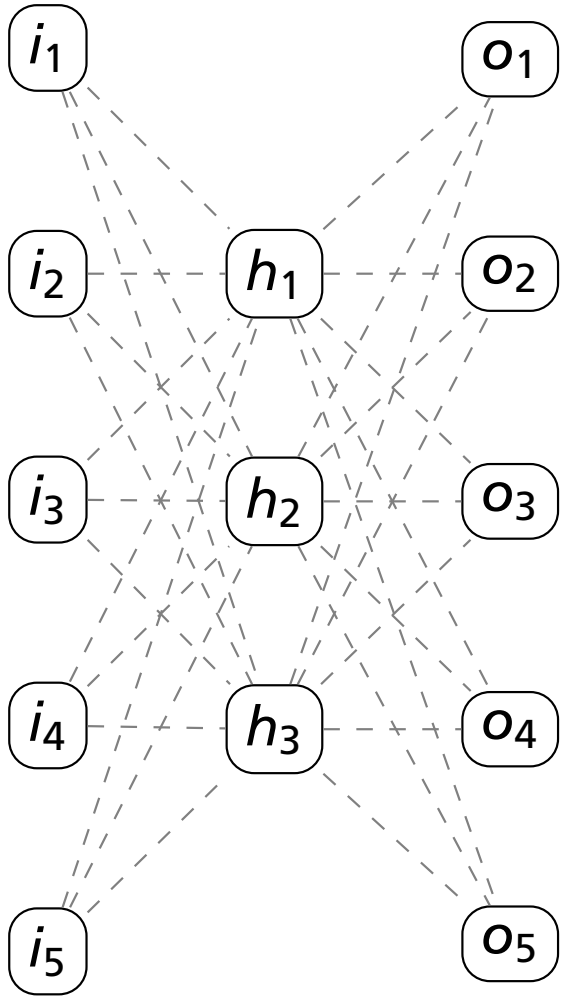
Autoencoder-based Detection



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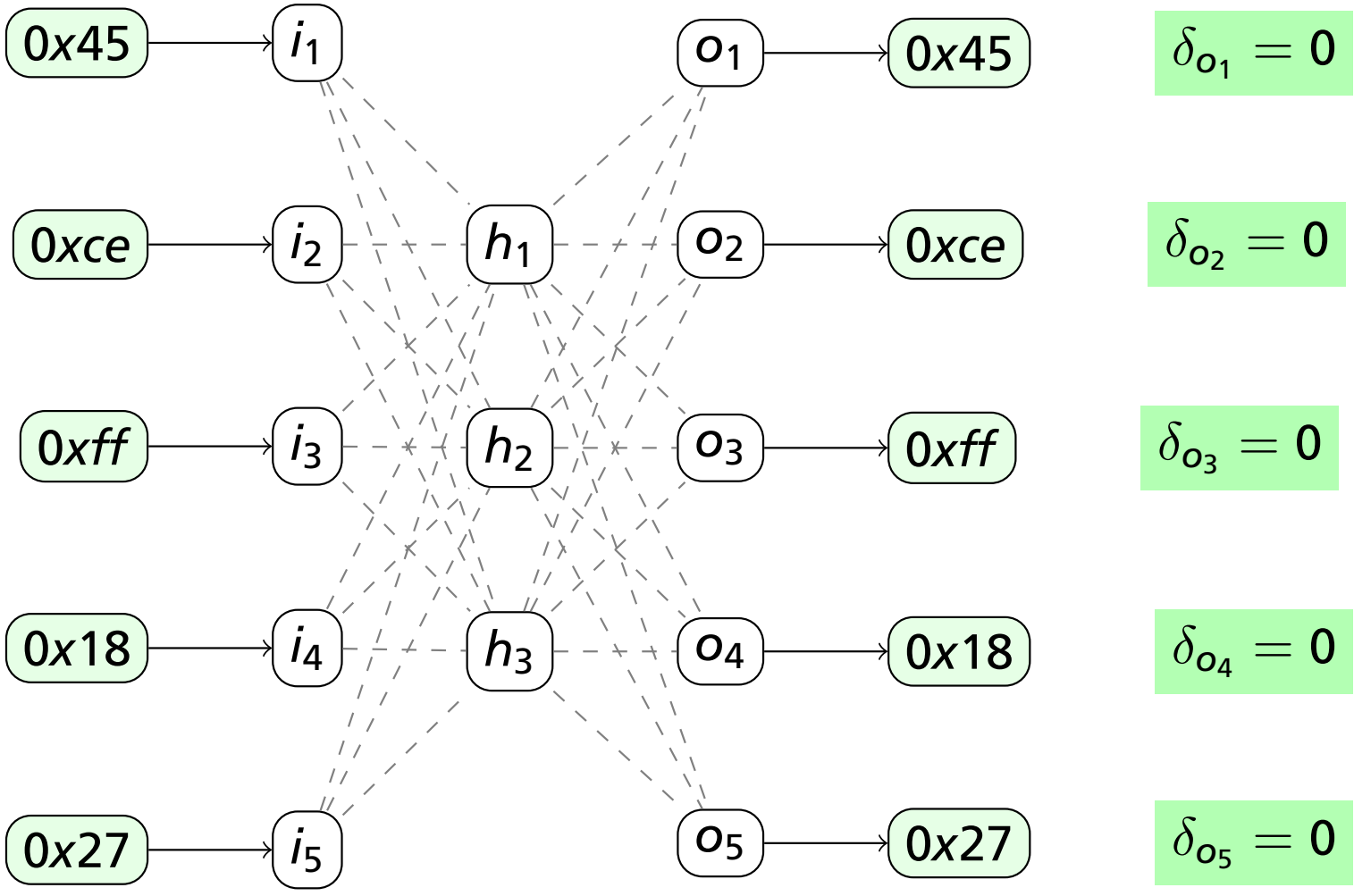
Autoencoder-based Detection



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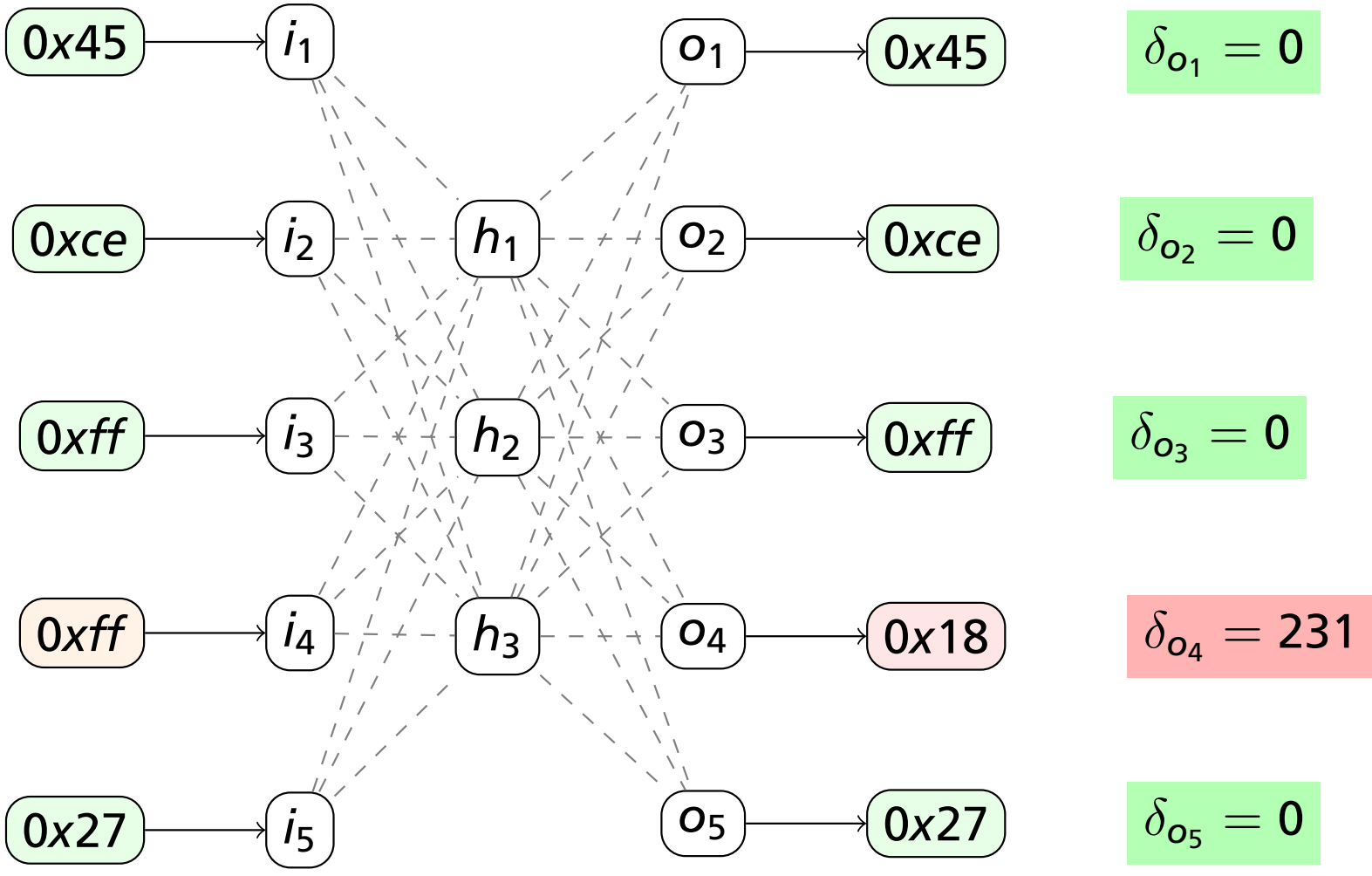

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SDA

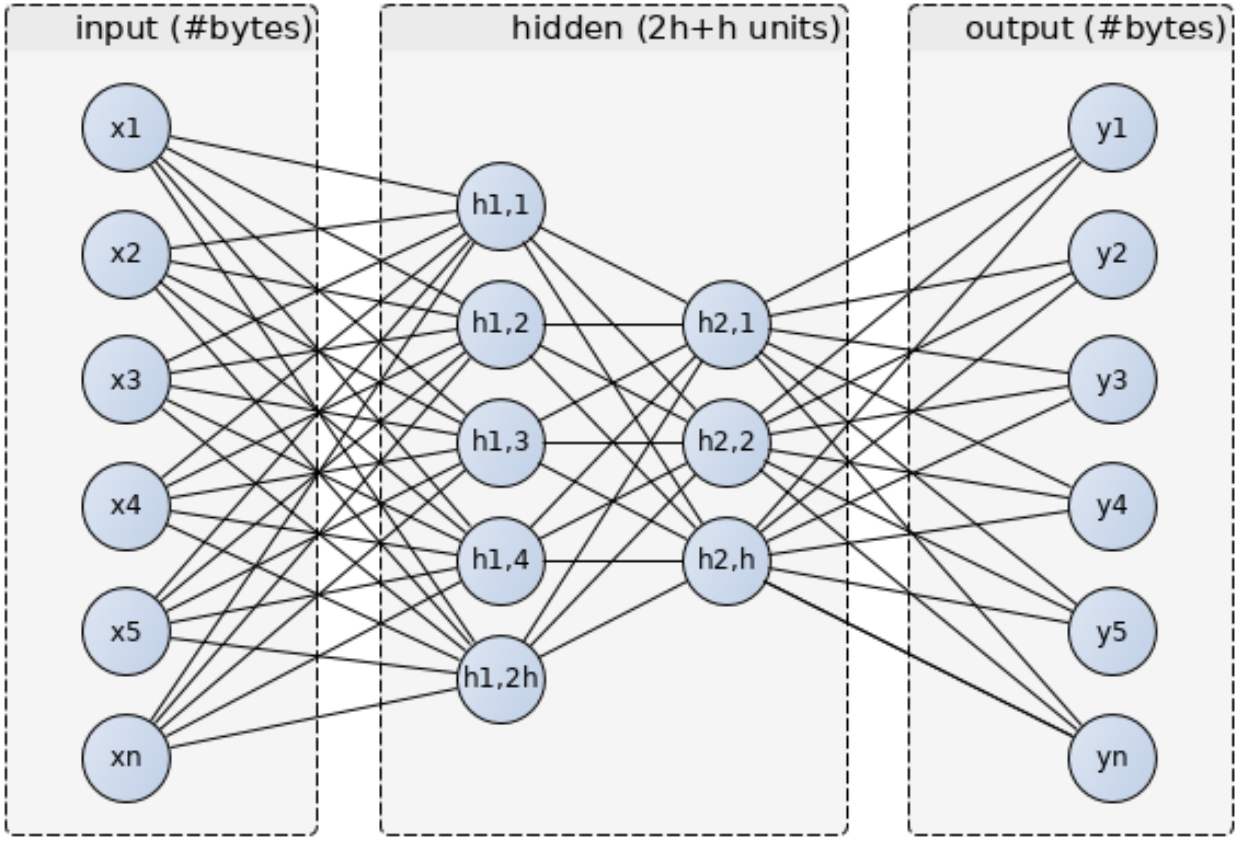

Figure: Stacked auto-encoders.

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Experiments

Modbus dataset

- labeled network packets
- several traces with and without attacks

SWaT dataset

- large dataset (~500GB)
- traces from several days with and without attacks
- pcap traces not labeled

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Modbus dataset – training data

Figure: RMSE on the `run1_3rtu_2s` trace.

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Modbus dataset – validation data

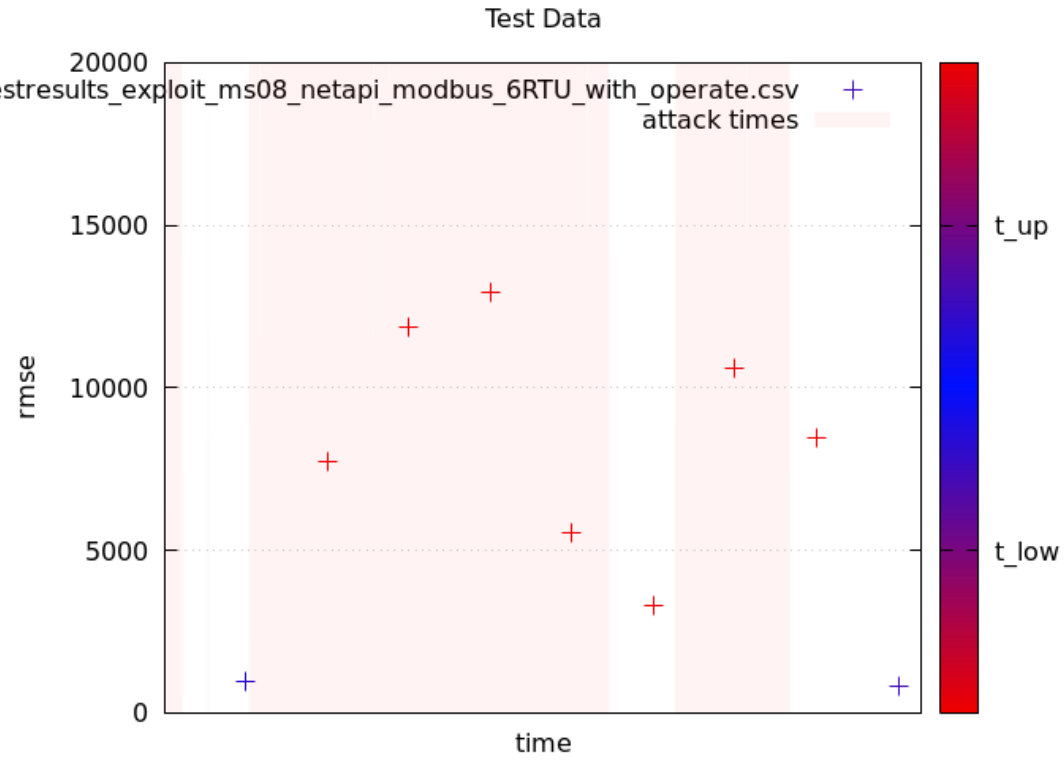

Figure: RMSE on the `exploit_ms08_netapi_modbus_6RTU_with_operate` trace.

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Modbus dataset – validation data

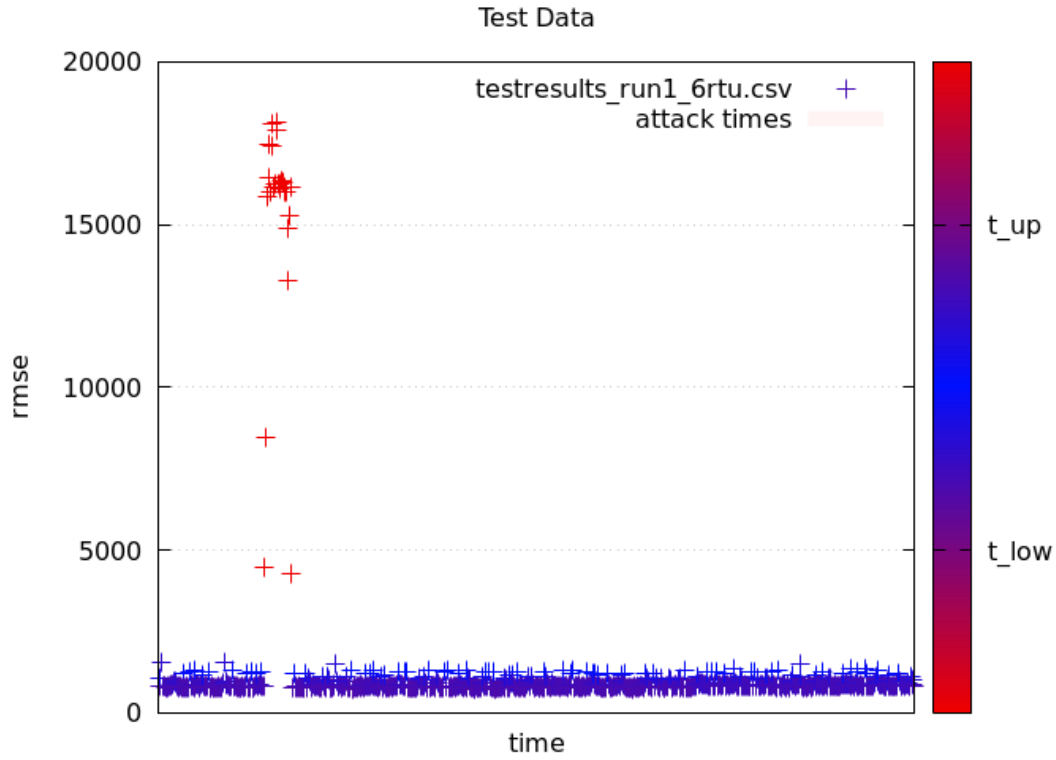

Figure: RMSE on the `run1_6rtu` trace.

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SWaT dataset

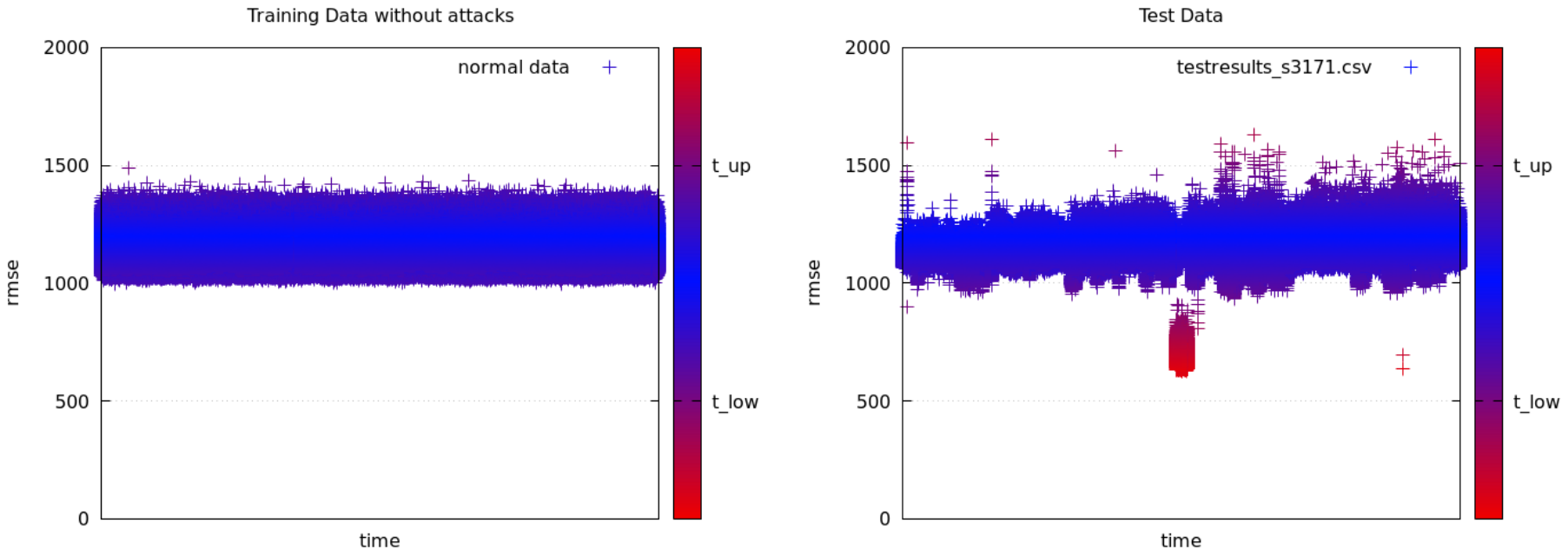

Figure: Results on SWaT dataset.

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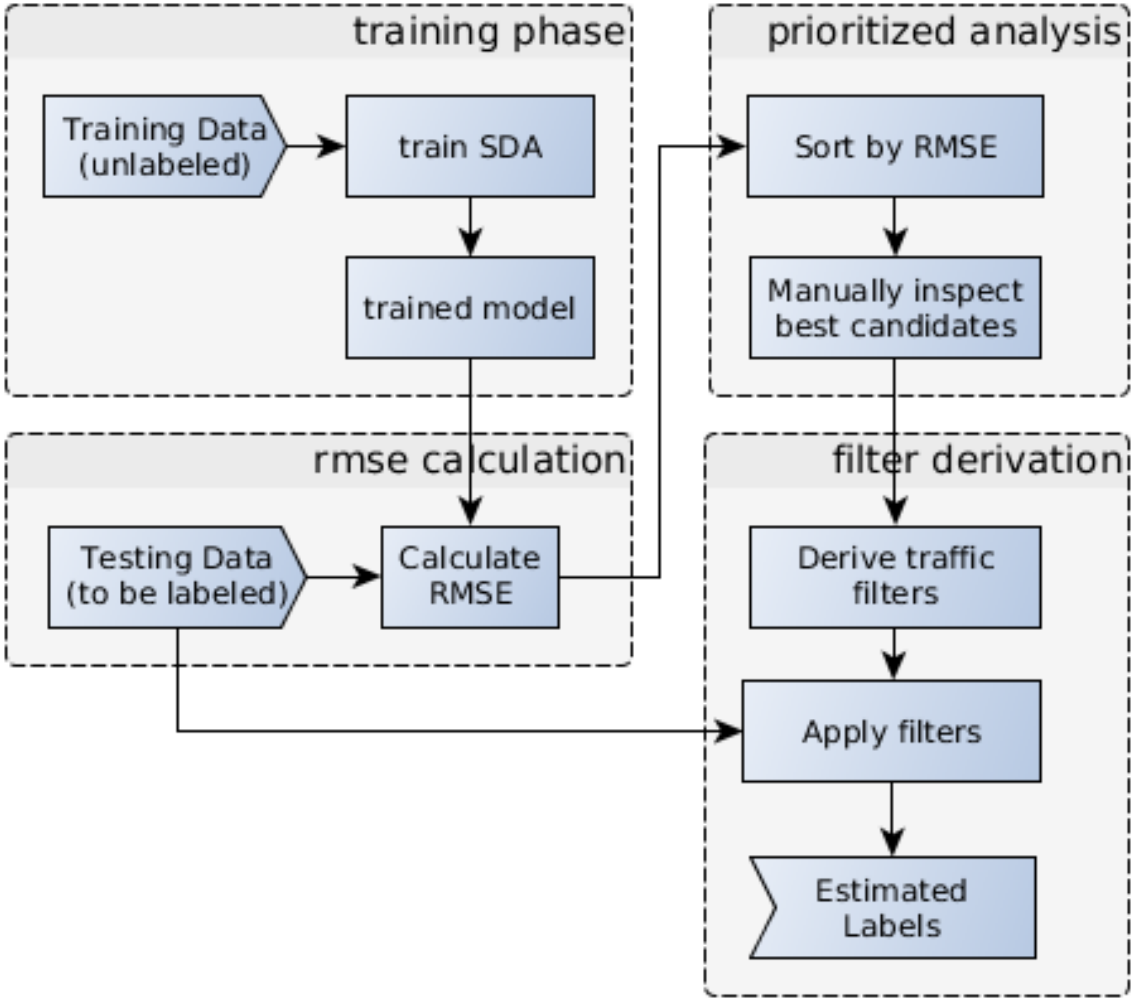
Label Estimation



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Labels Estimated

dupack duplicated acknowledgements
tcp.analysis.duplicate_ack

retransmit retransmitted packets
tcp.analysis.retransmission or tcp.analysis.fast_retransmission

unknownproto-tls newly introduced TLS layers
manual analysis

tcpreset connection resets using TCP RST flag
tcp.flags.reset==1

synflood flooding using TCP SYN packets
transum.status=="Response missing" and tcp.connection.syn

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SWaT dataset, detailed results

Line		dupack	retransmit	unknownproto-tls
1	precision	6.38%	2.22%	4.35%
2	recall	3.95%	1.00%	0.38%
3	f1	4.88%	1.38%	0.70%

Table: Anomaly detection performance in problematic scenarios.

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SWaT dataset, detailed results

Line		tcpreset	synflood
1	precision	99.80%	99.80%
2	recall	99.77%	99.99%
3	f1	99.78%	99.89%

Table: Anomaly detection performance in well-working scenarios.

Naive classifier Using packet length $\rightarrow$ 0% f1-score

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Conclusion

Where Cyber-Physical System Networks

→ **SWaT** (EtherNet/IP) and **Modbus** datasets for validation

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Why High-Performance
→ fast **data acquisition** omitting packet parsing
Unsupervised
→ **feature learning** using SDAs

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Why High-Performance
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For what Detection in proprietary and/or binary protocols
→ up to **99%** f1-scores

Contact Information

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