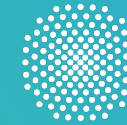**HSE**
Radiation Protection

University of Stuttgart
Institute of Machine Components

UNI STUTTGART

Integrating system knowledge in unsupervised anomaly detection algorithms for simulation-based failure prediction of electronic circuits

Felix Waldhauser, Hamza Boukabache, Martin Dazer, Daniel Perrin, Stefan Roesler

10/10/2023

ICALEPCS 2023

Conflicting goals: safety vs. availability

CERN Radiation Monitoring Electronics (**CROME**)
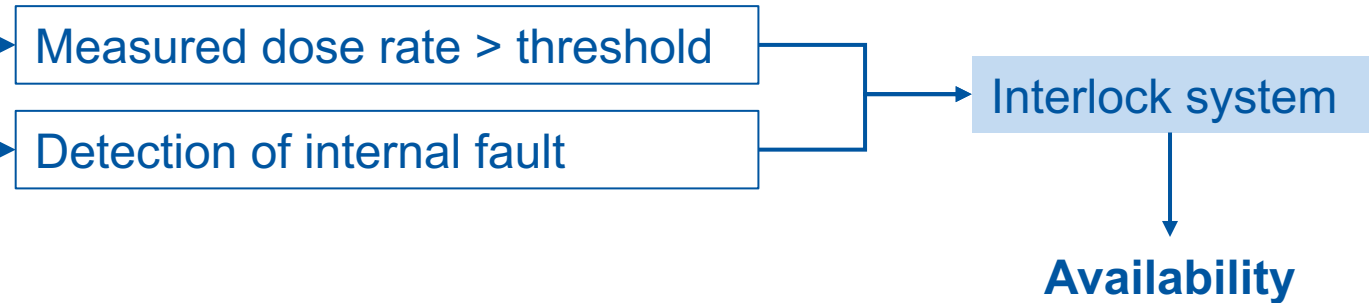- High reliability
- High failure detectability

Conflicting goals: Safety vs. Availability

CERN Radiation Monitoring Electronics (**CROME**)
- High reliability
- High failure detectability

Measured dose rate > threshold

Detection of internal fault

Interlock system

Availability

Data-driven condition monitoring and **failure prediction**
→ Reduce **unexpected failures** by predictive maintenance

Linking anomalies to the device condition

Operational datasets

↓

Unsupervised anomaly detection

Device condition

↓

↕ ?

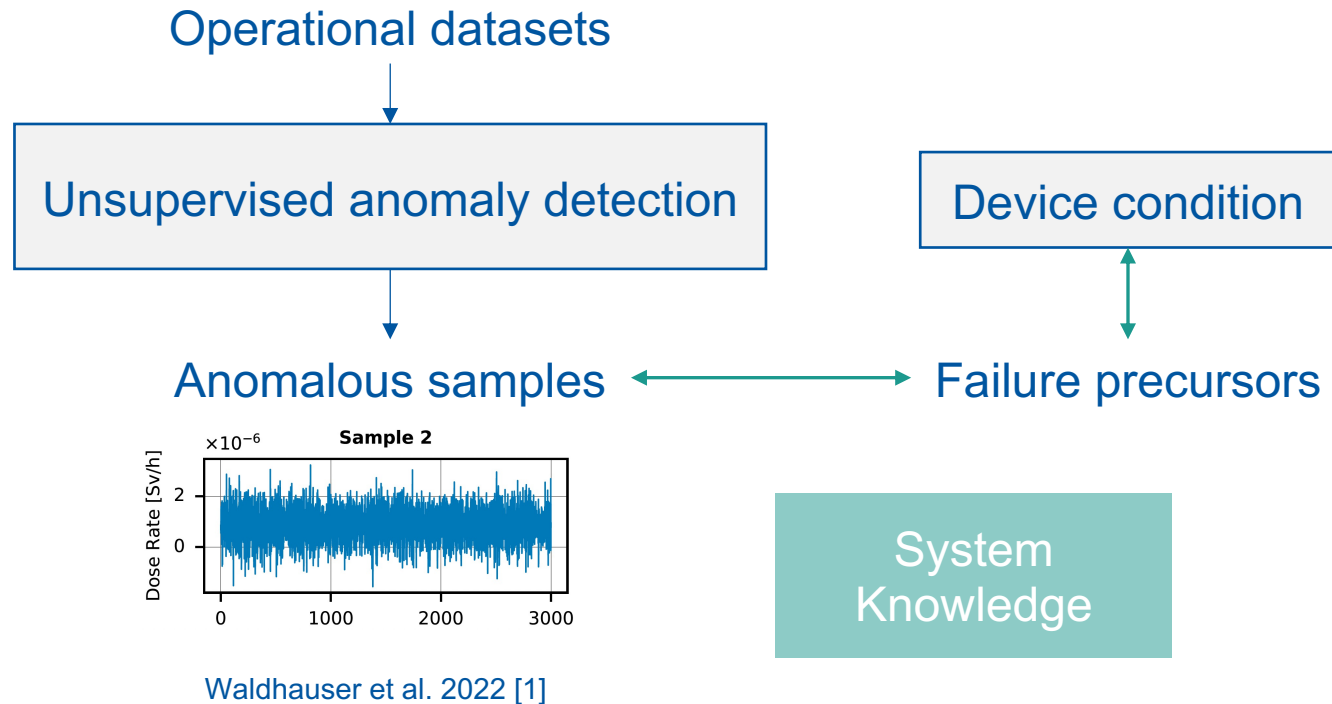Anomalous samples ←---- ? ----→ Failure precursors
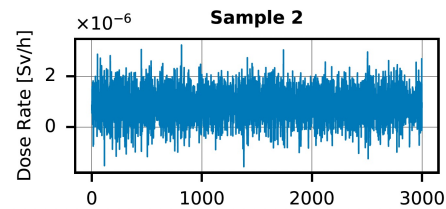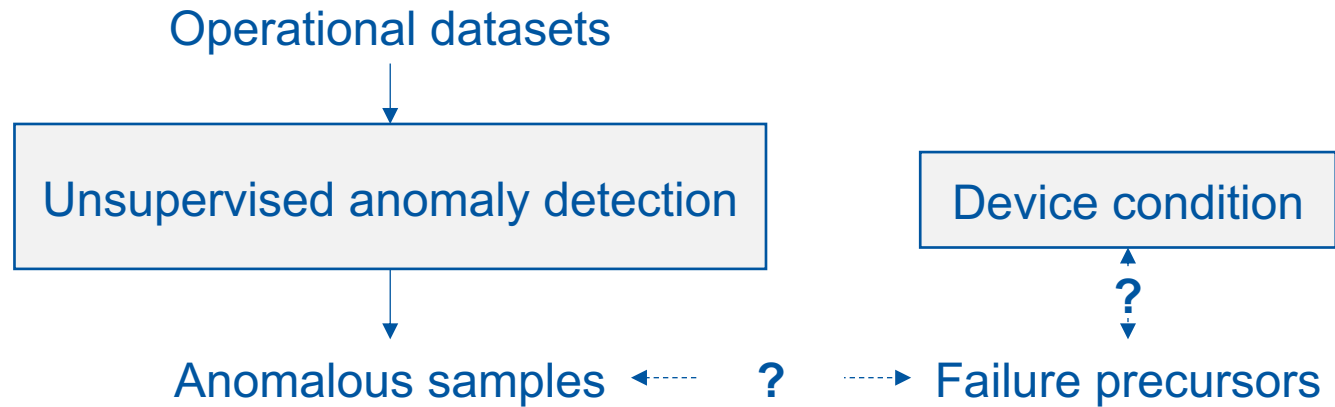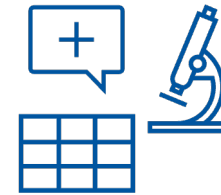

Waldhauser et al. 2022 [1]

[1] Waldhauser et al., "Wavelet-based noise extraction for anomaly detection applied to safety-critical electronics at CERN," in Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022), 2022

Linking anomalies to the device condition

Operational datasets

Unsupervised anomaly detection

Device condition

Anomalous samples ⟷ Failure precursors

Waldhauser et al. 2022 [1]

System Knowledge

Most **efficient** approach?

Type & extend of system knowledge

Anomaly detection algorithm

Use synthetic datasets from **simulations** to evaluate approaches

Here: SPICE simulations of CROME power supply circuit

[1] Waldhauser et al., "Wavelet-based noise extraction for anomaly detection applied to safety-critical electronics at CERN," in Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022), 2022

Agenda

1. Methodology

2. Integration of System Knowledge

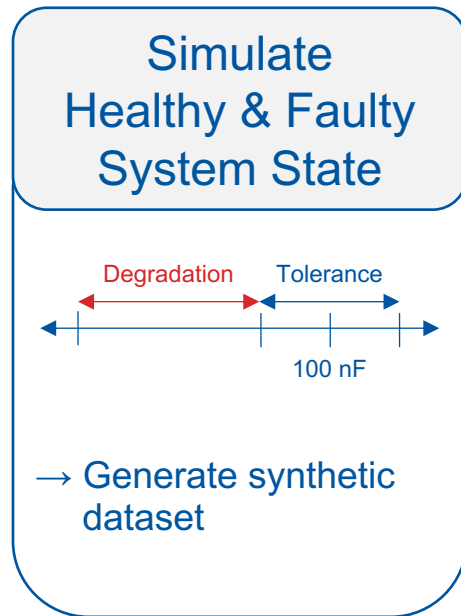3. Benchmarking Results

4. Conclusion and Outlook

Agenda

1. Methodology

2. Integration of System Knowledge

3. Benchmarking Results
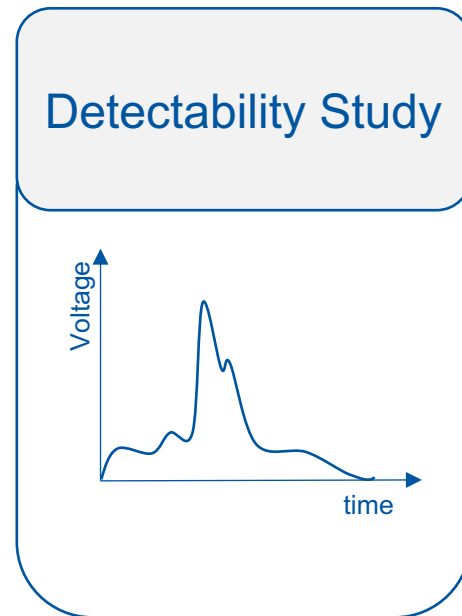
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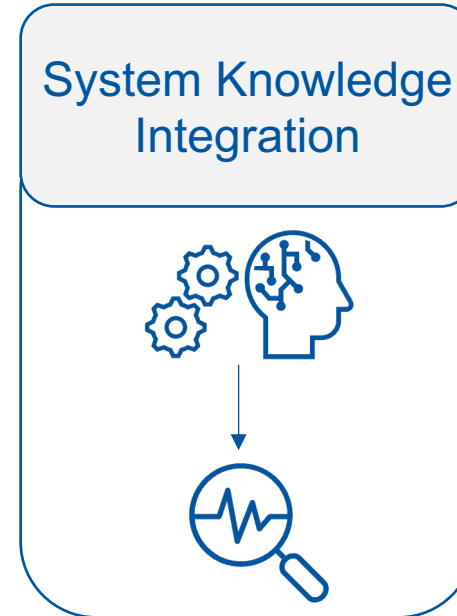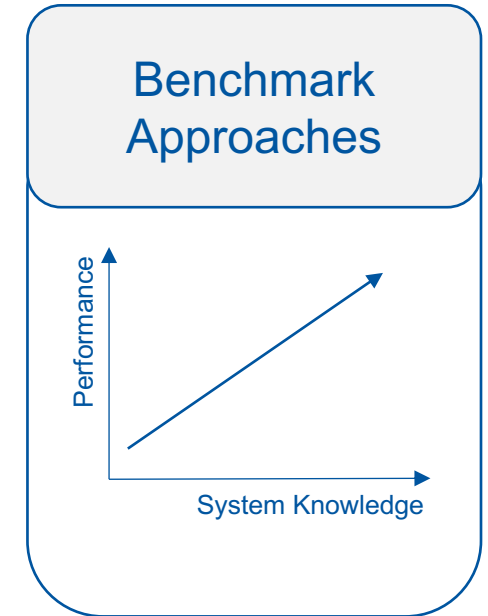# Synthetic datasets from simulations allow benchmarking of approaches

I — Simulate Healthy & Faulty System State — Degradation / Tolerance / 100 nF → Generate synthetic dataset

II — Detectability Study — Voltage vs time

III — System Knowledge Integration

IV — Benchmark Approaches — Performance vs System Knowledge
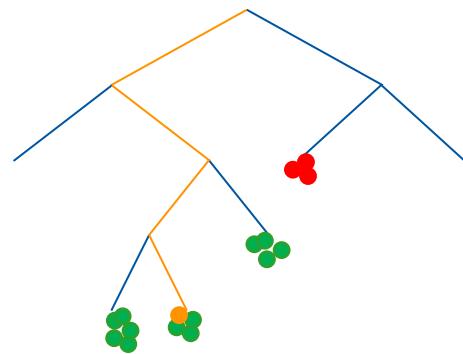
HSE
Radiation Protection

Agenda

1. Methodology

2. Integration of System Knowledge

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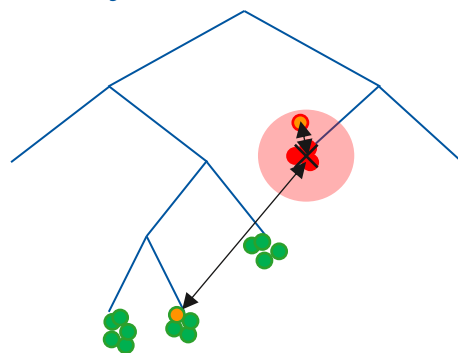
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Integration of system knowledge into anomaly detection algorithms

Isolation Forest (IF)

Anomaly score:
Path length

Hybrid Isolation Forest (HIF)

Anomaly score:
Path length
+
Distance

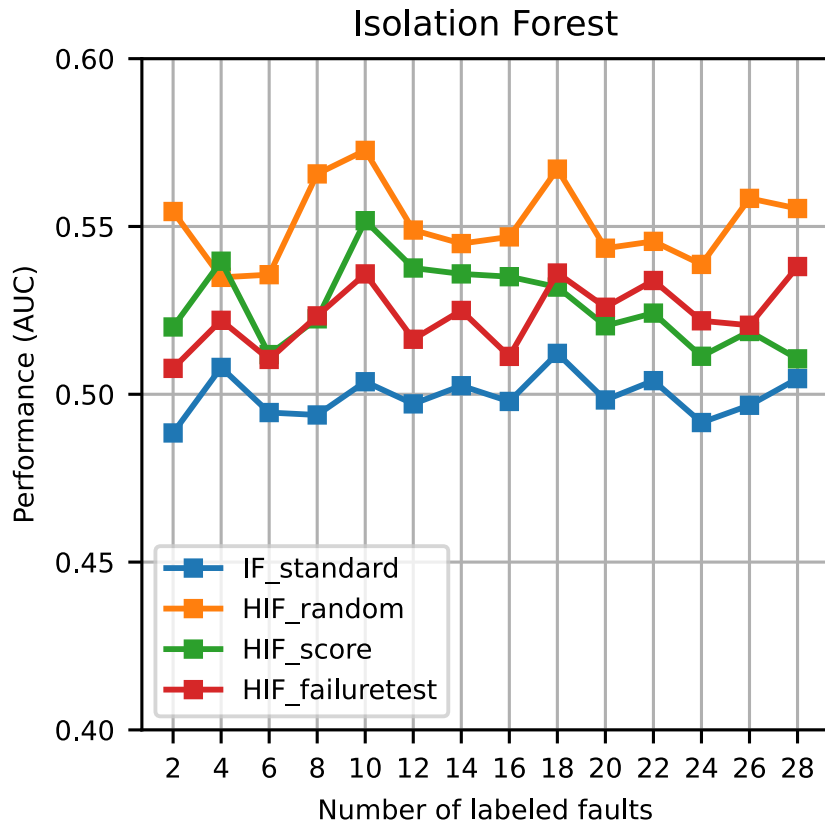| Algorithm	System knowledge source
IF_standard	None (unsupervised)
HIF_random	Expert review, random selection
HIF_score	Expert review, score-based selection
HIF_failuretest	Synthetic tests triggering failures

Goal: Establish link between anomalies and failures
→ here: increase classification **performance** of anomaly
    detection

Agenda

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

| Algorithm	System knowledge source
IF_standard	None (unsupervised)
HIF_random	Expert review, random selection
HIF_score	Expert review, score-based selection
HIF_failuretest	Synthetic tests triggering failures

- Score-based expert review: decreasing performance
- Random expert review: classification **error-prone**

Most promising approach: generate knowledge about the failure behavior using **synthetic tests**

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

Isolation Forest

Performance does not significantly increase with more supplied labeled faults – **why?**
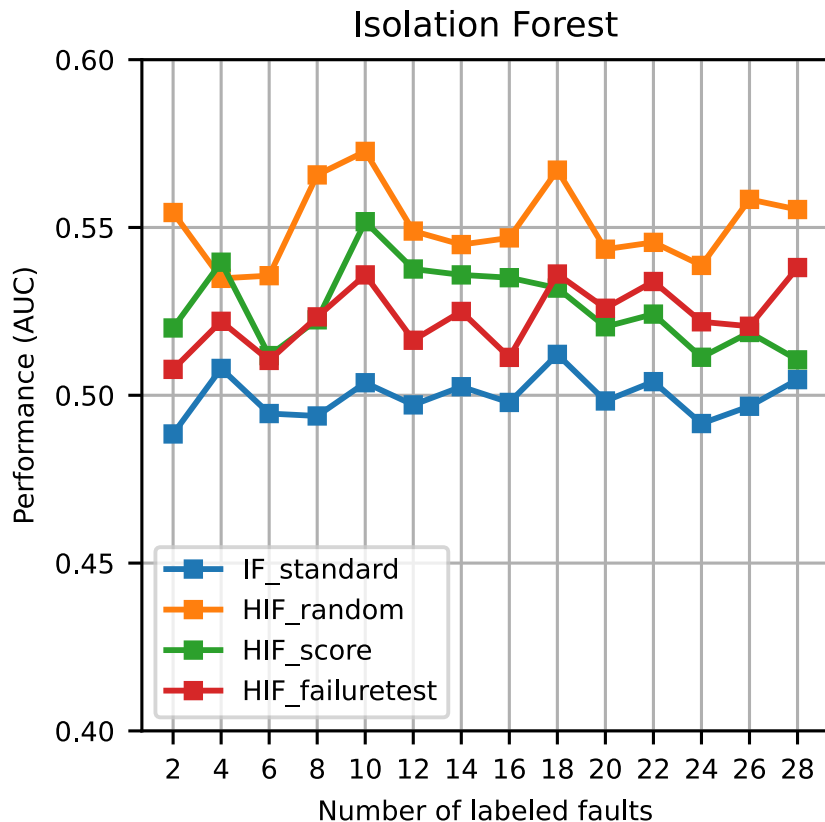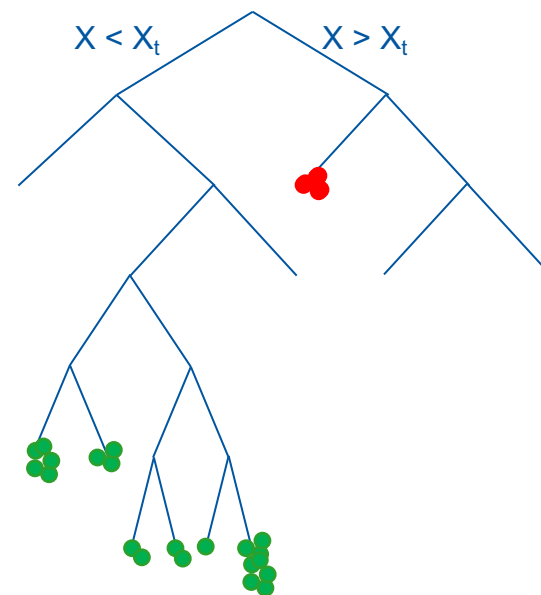
$X < X_t$ $X > X_t$
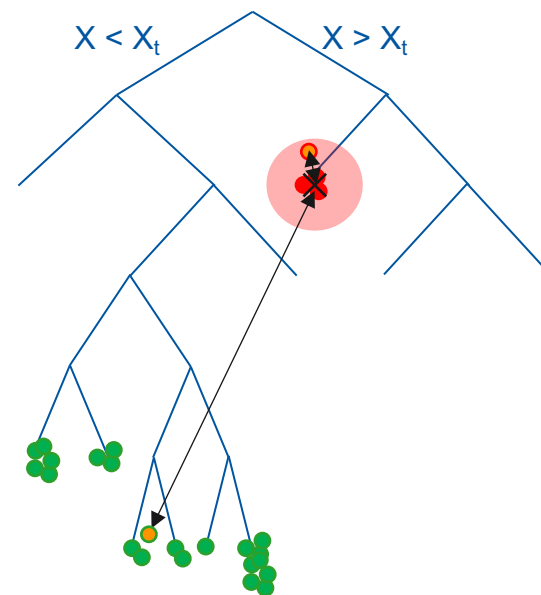
Ideal setting

Anomaly score = Path length + Distance (HIF)

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

Isolation Forest

Performance does not significantly increase with more supplied labeled faults – **why?**
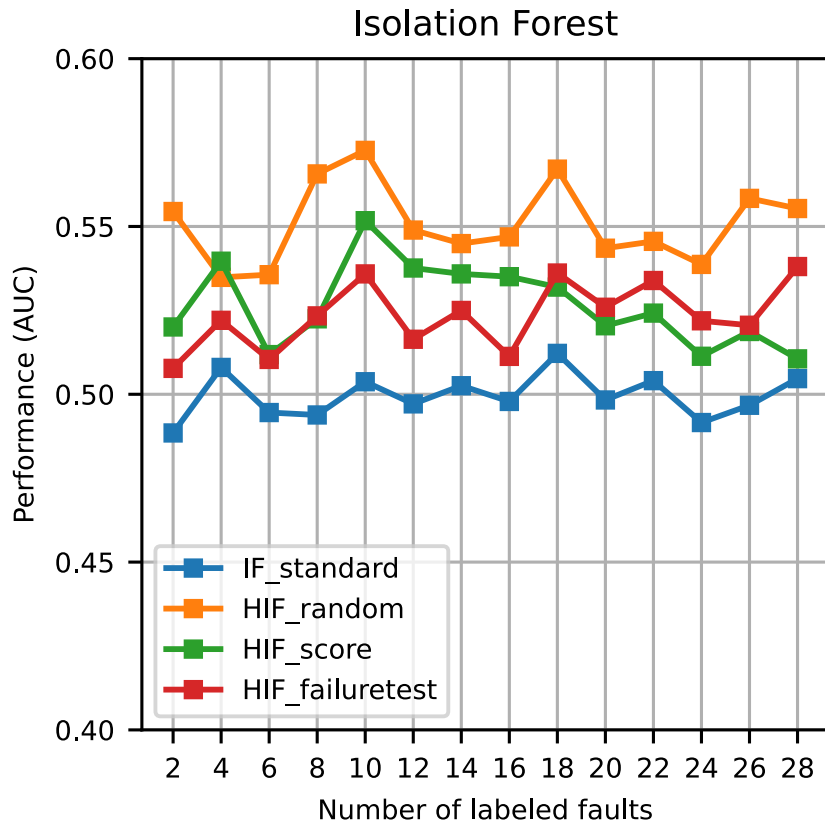
$X < X_t$ $X > X_t$

This use case:

Anomaly score = Path length + Distance (HIF)

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

Isolation Forest

Performance does not significantly increase with more supplied labeled faults – **why?**
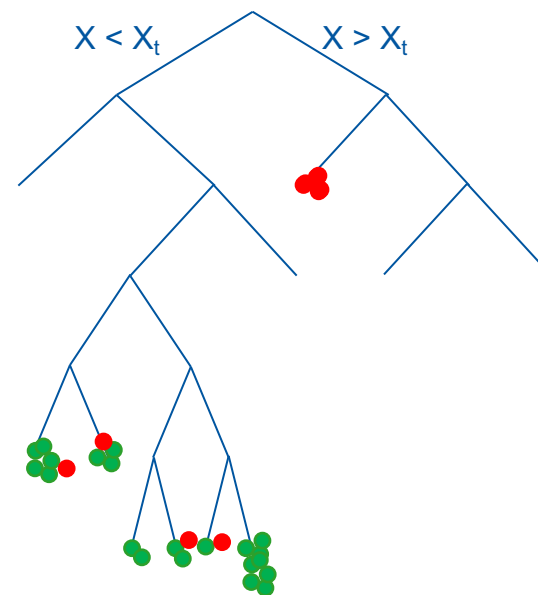
$X < X_t$ $X > X_t$

This use case:
- Faults **masked** as healthy

Anomaly score = Path length + Distance (HIF)

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

Isolation Forest

Performance does not significantly increase with more supplied labeled faults – **why?**

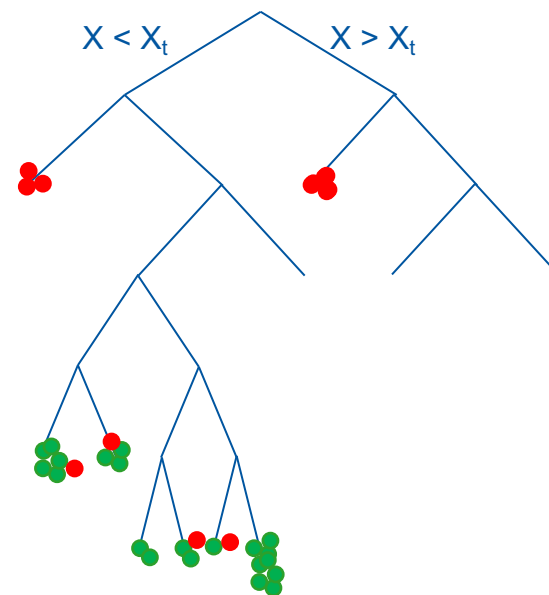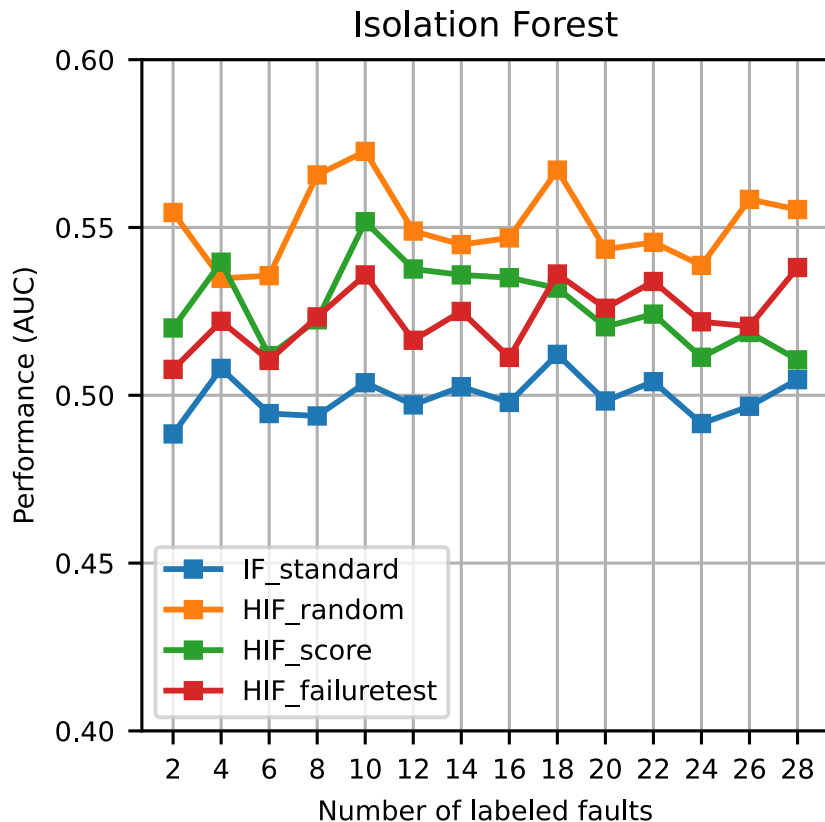$X < X_t$ $X > X_t$

This use case:
- Faults **masked** as healthy
- **Diverse** failure characteristics

Anomaly score = Path length + Distance (HIF)

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

Isolation Forest

Performance does not significantly increase with more supplied labeled faults – **why?**

$X < X_t$ $X > X_t$

This use case:
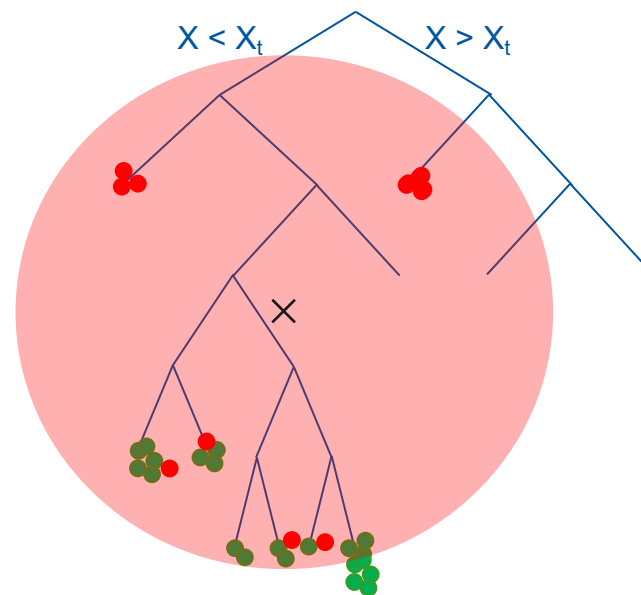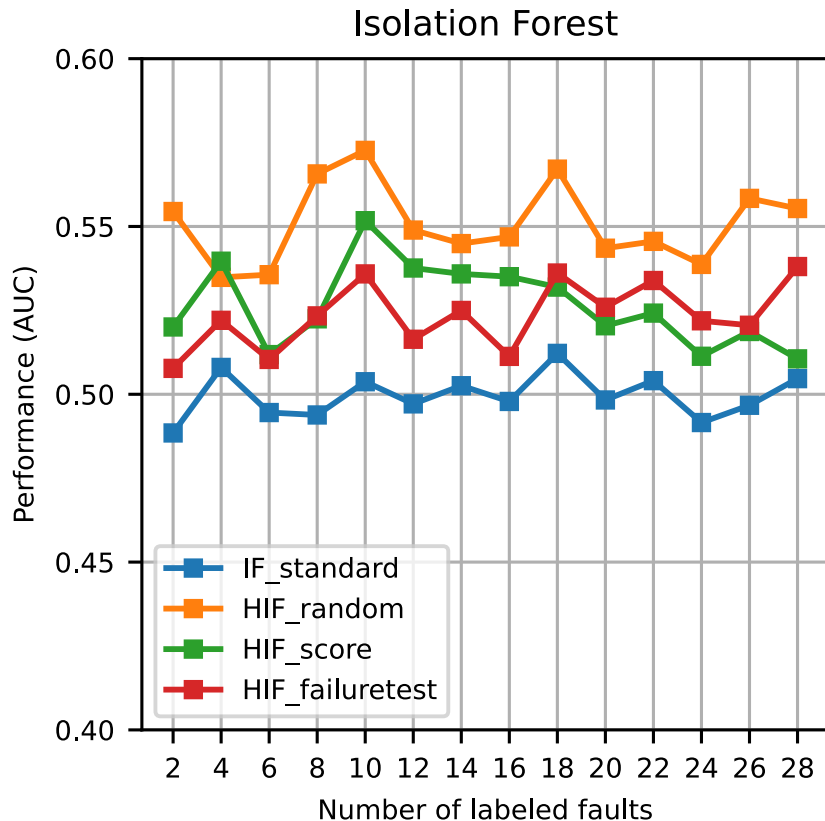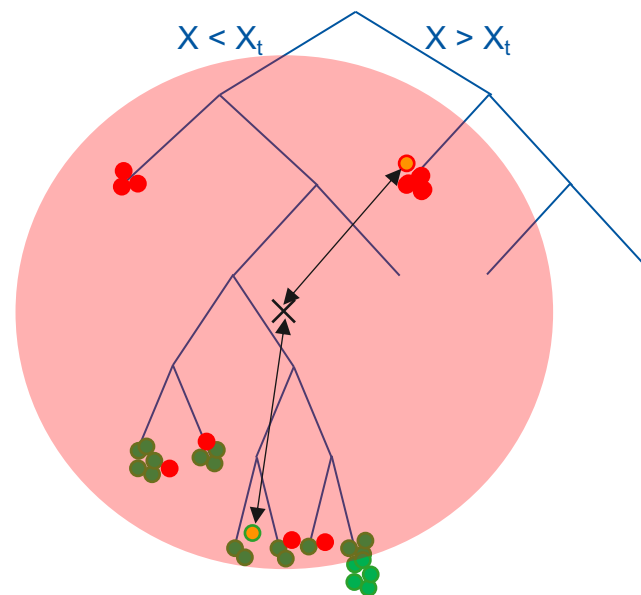- Faults **masked** as healthy
- **Diverse** failure characteristics

Anomaly score = Path length + Distance (HIF)

Hybrid Isolation Forest algorithm benefits from supplied labeled faults

Isolation Forest

Performance (AUC) vs Number of labeled faults

Legend:
- IF_standard
- HIF_random
- HIF_score
- HIF_failuretest

Performance does not significantly increase with more supplied labeled faults – **why?**

$X < X_t$ $X > X_t$

This use case:
- Faults **masked** as healthy
- **Diverse** failure characteristics

Anomaly score = Path length + Distance (HIF)

HSE
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Agenda

Conclusion and Outlook

Simulation-based benchmarking of anomaly detection performance

- Select approach at early-stage to ensure efficient usage of system knowledge

- Study interaction between system knowledge and algorithm performance

- Here: hardware tests are preferable over expert review of anomalies

Outlook:

- Restrict failure prediction (detectable failures, system functionality)

- Improve anomaly detection performance

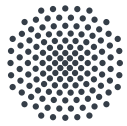- Simulation of operational datasets

Thank you!

Felix Waldhauser

Radiation Protection – Instrumentation & Logistics

CERN

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phone   +41 22 76 66526