Data-driven Machine Condition Monitoring in Rotating Machinery

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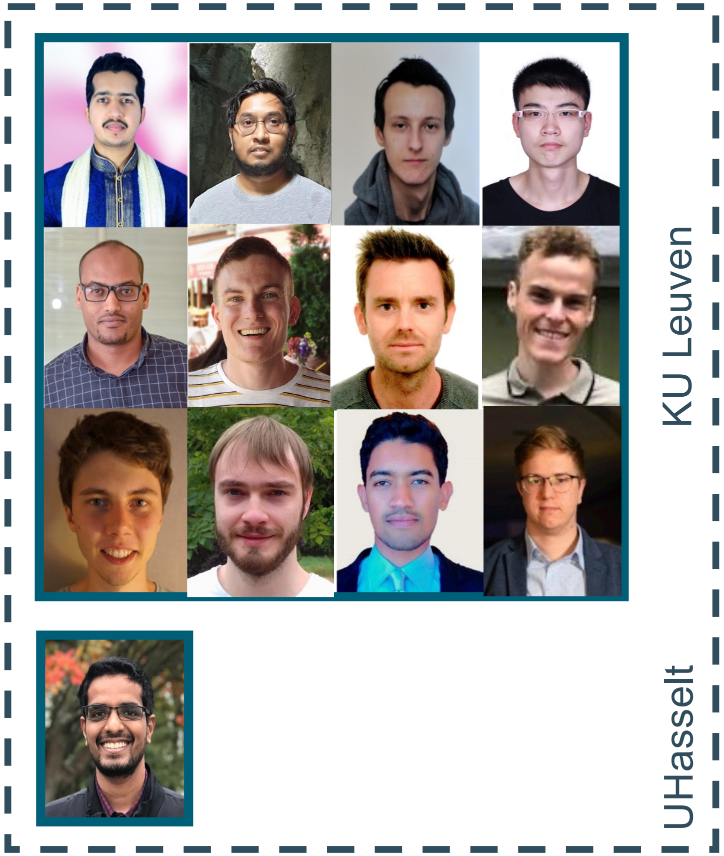
Overview

- DTAI@Geel
- Constraint guided deep learning
- Use-case: condition monitoring

DTAI@Geel

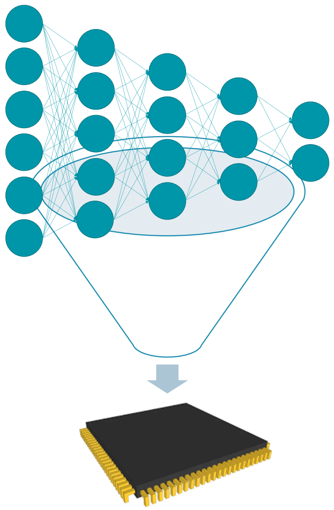
DTAI LEUVEN.AI FLANDERS MAKE DRIVING INNOVATION IN MANUFACTURING Advanced Integrated Sensing ADVISE

- DTAI@Geel people
    - 1 Professor
    - 2 FTE Postdoc
    - 11 FTE PhD
- Flanders Make Core Lab



DTAI@Geel
Common theme

Machine learning under limiting conditions

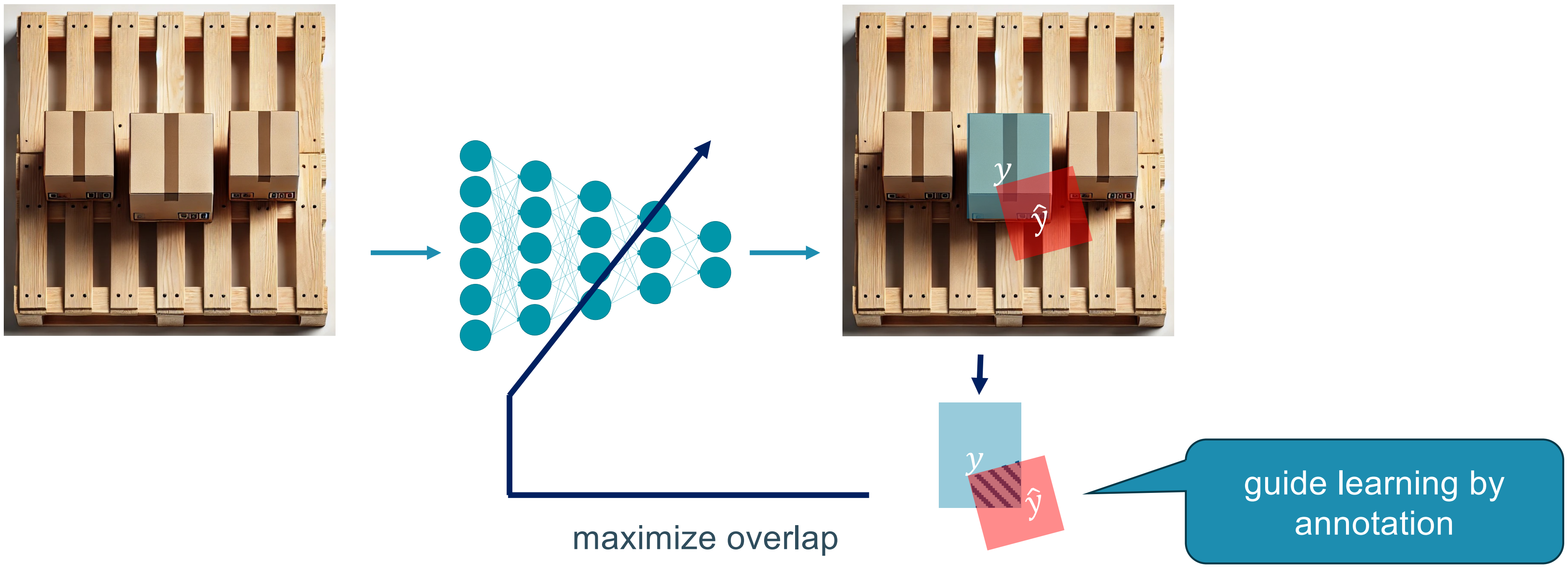


with a focus on (acoustic) time-series signals

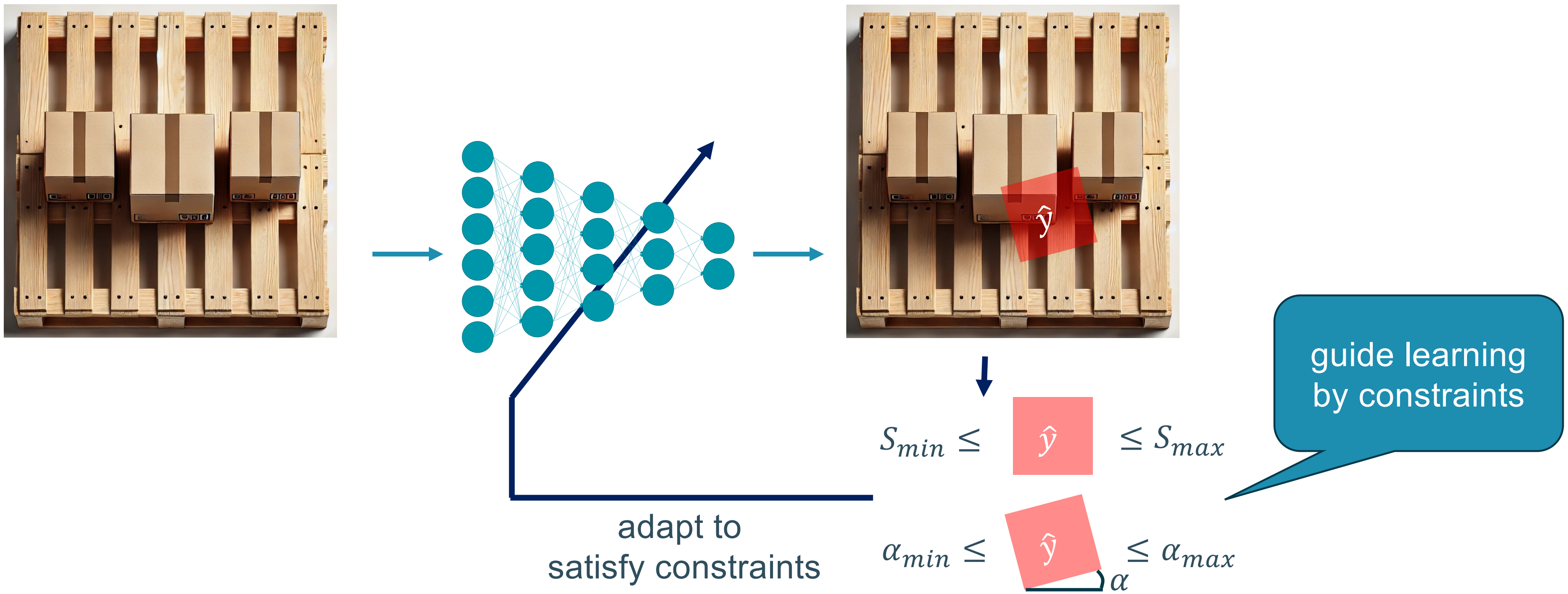
Overview

- DTAI@Geel
- **Constraint guided deep learning**
- Use-case: condition monitoring

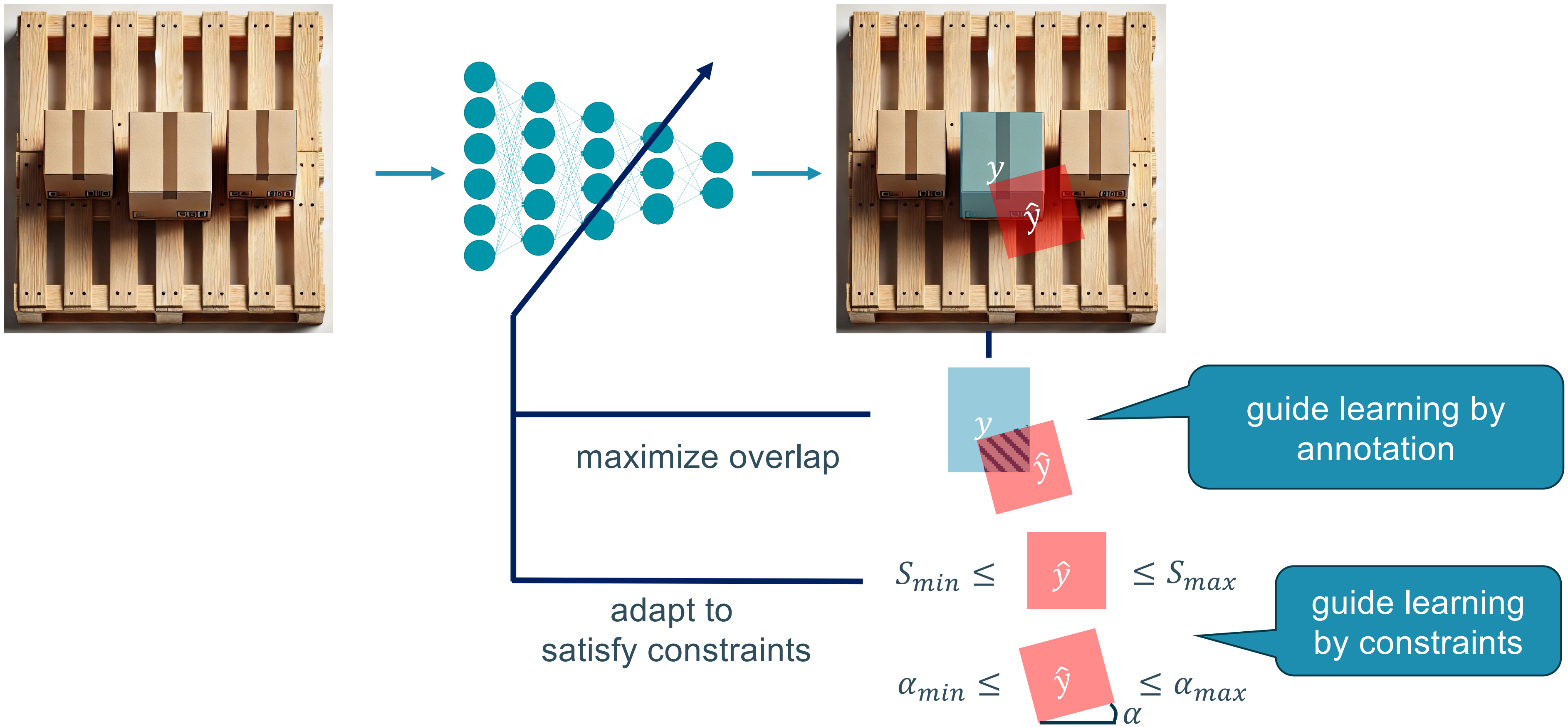
Annotation guided (supervised) deep learning



Constraint guided deep learning



In-house framework:
Annotation and constraint guided deep learning (CGGD)



[1] Q. Van Baelen et al., "Constraint guided gradient descent: Training with inequality constraints with applications in regression and semantic segmentation", Neurocomputing, Volume 556, 2023.

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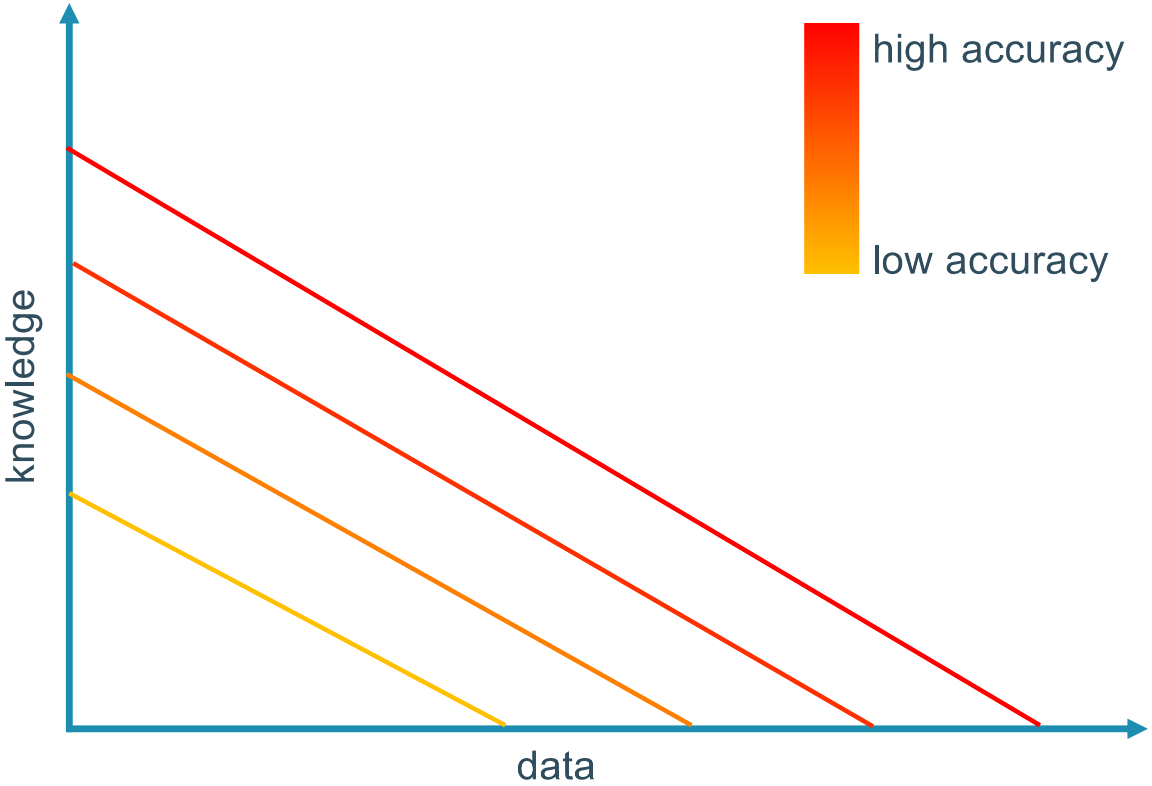

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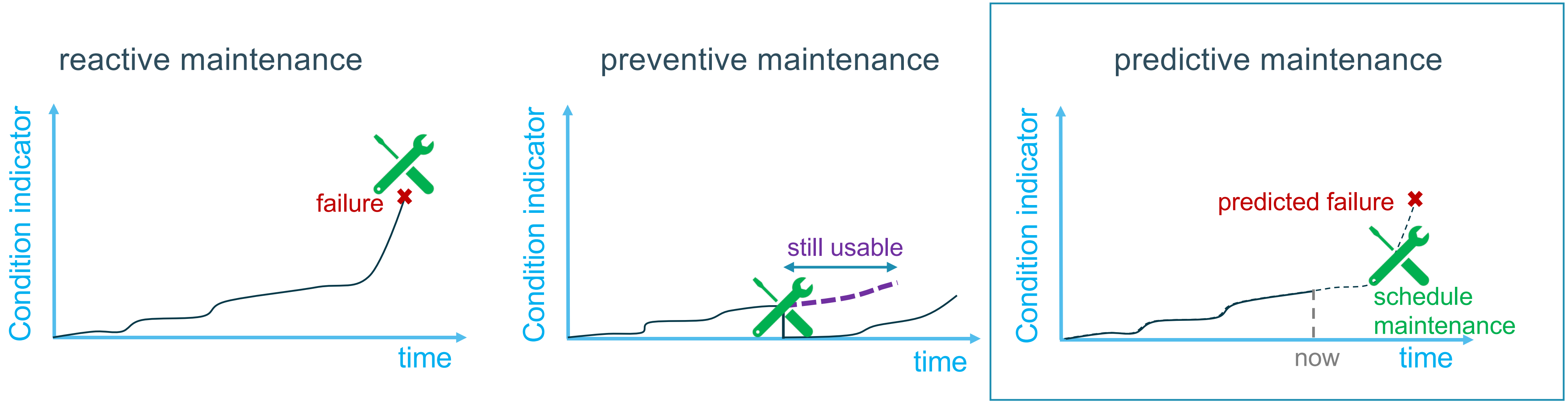
Overview

- Research focus
- Constraint guided deep learning
- **Use-case: condition monitoring**

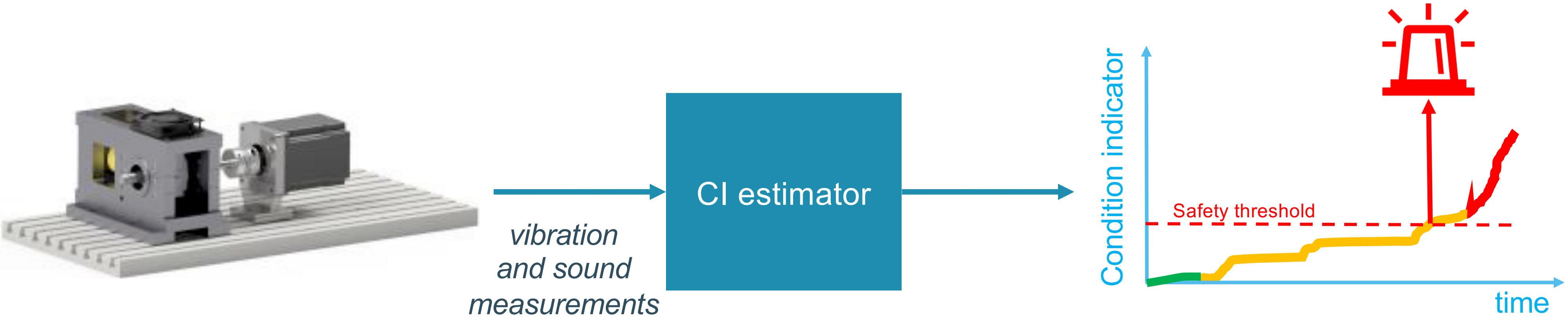
Use-case: condition monitoring



our focus

Use-case: condition monitoring

Goal: data-driven learning of a (high quality) condition score to enable incipiant defect detection in rolling element bearings

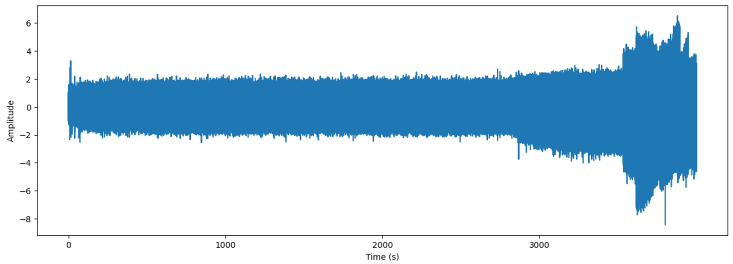


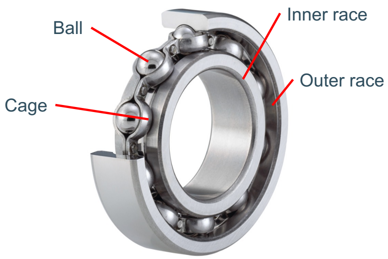
Use-case: condition monitoring

Baseline: handcrafted condition indicators

Hand-crafted approach:

- set of rules based on domain knowledge
- simple (univariate) checks
- might be time consuming





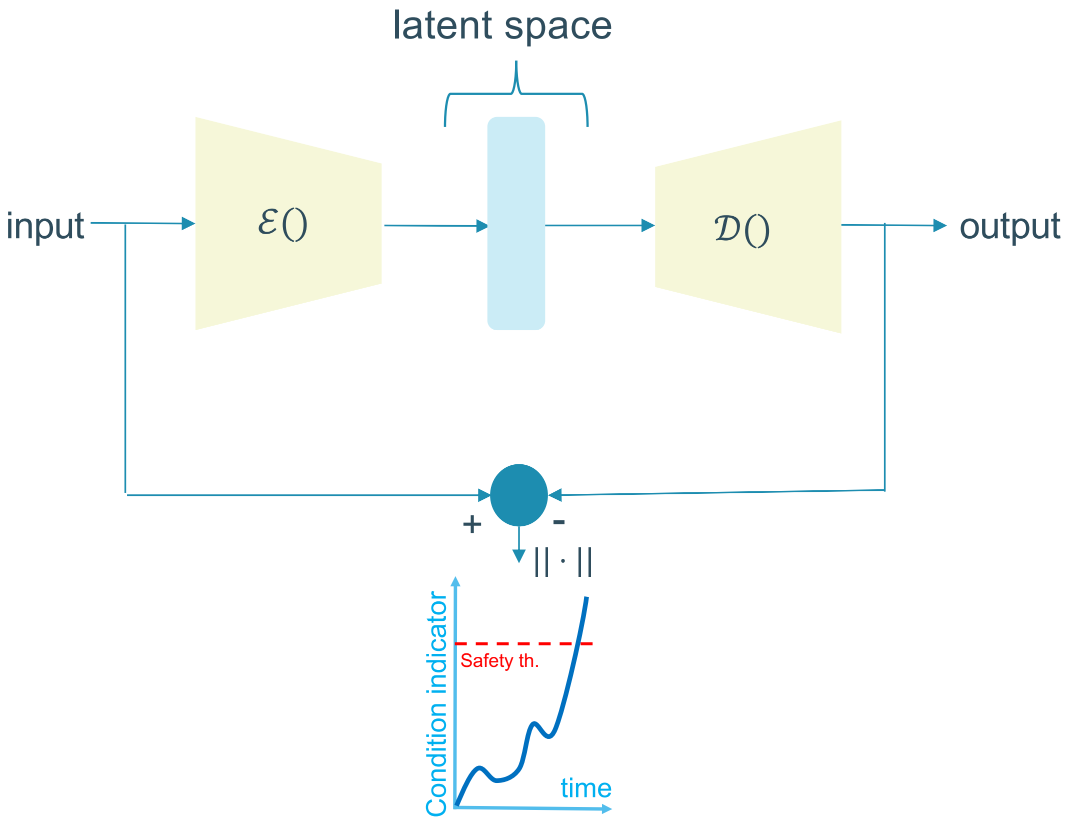
Handcrafted condition indicators
RMS
Kurtosis
BPFI
BPFO
BSF
…

DTAI
Geel Campus
Faculty of Engineering Technology
KU LEUVEN GEEL

Use-case: condition monitoring
Baseline: data-driven based condition indicator

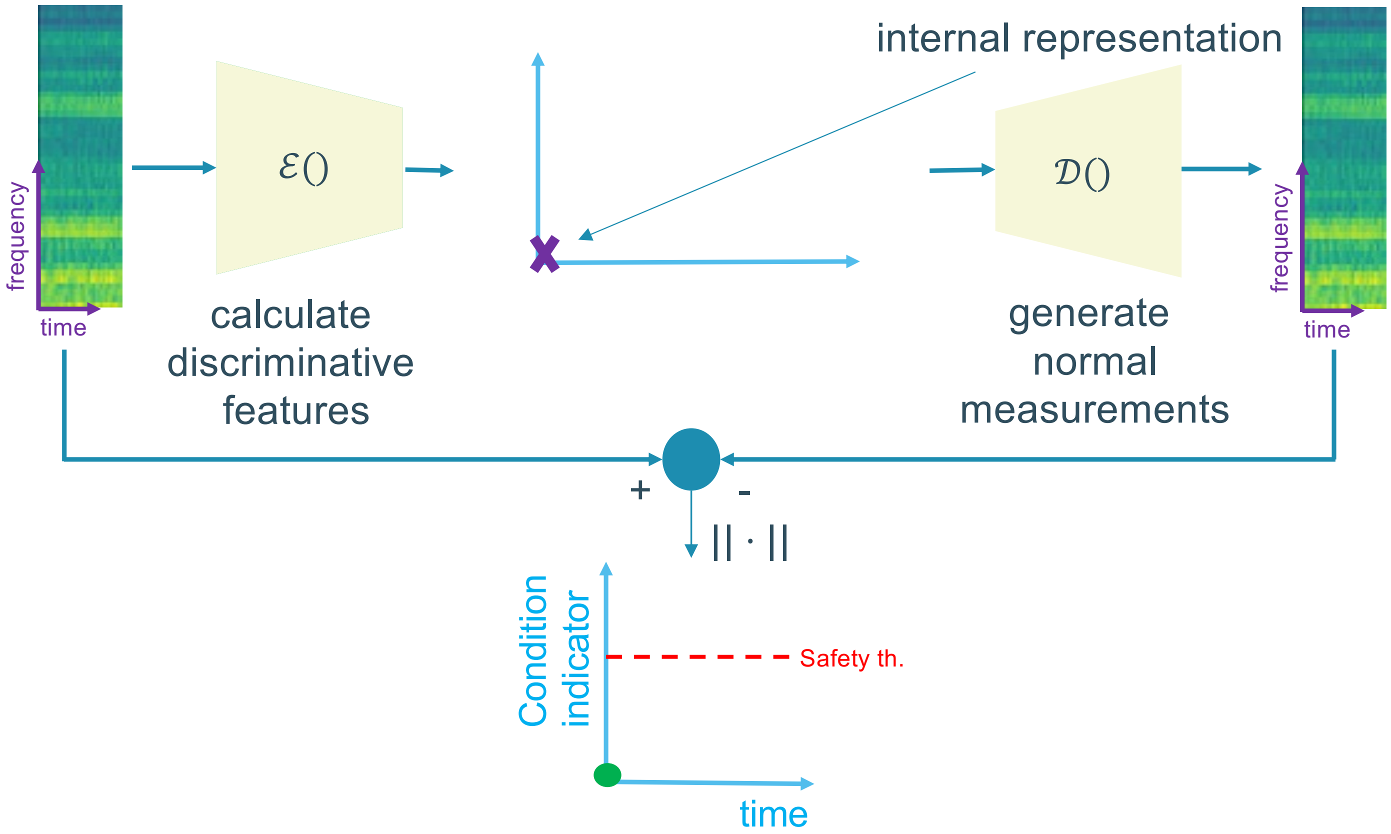
Data-driven approach:

- learn patterns that indicate condition automatically
- more advanced multivariate checks possible
- less engineering time
- e.g. AE based CI estimation



Use-case: condition monitoring

Baseline: data-driven based condition indicator



Use-case: condition monitoring

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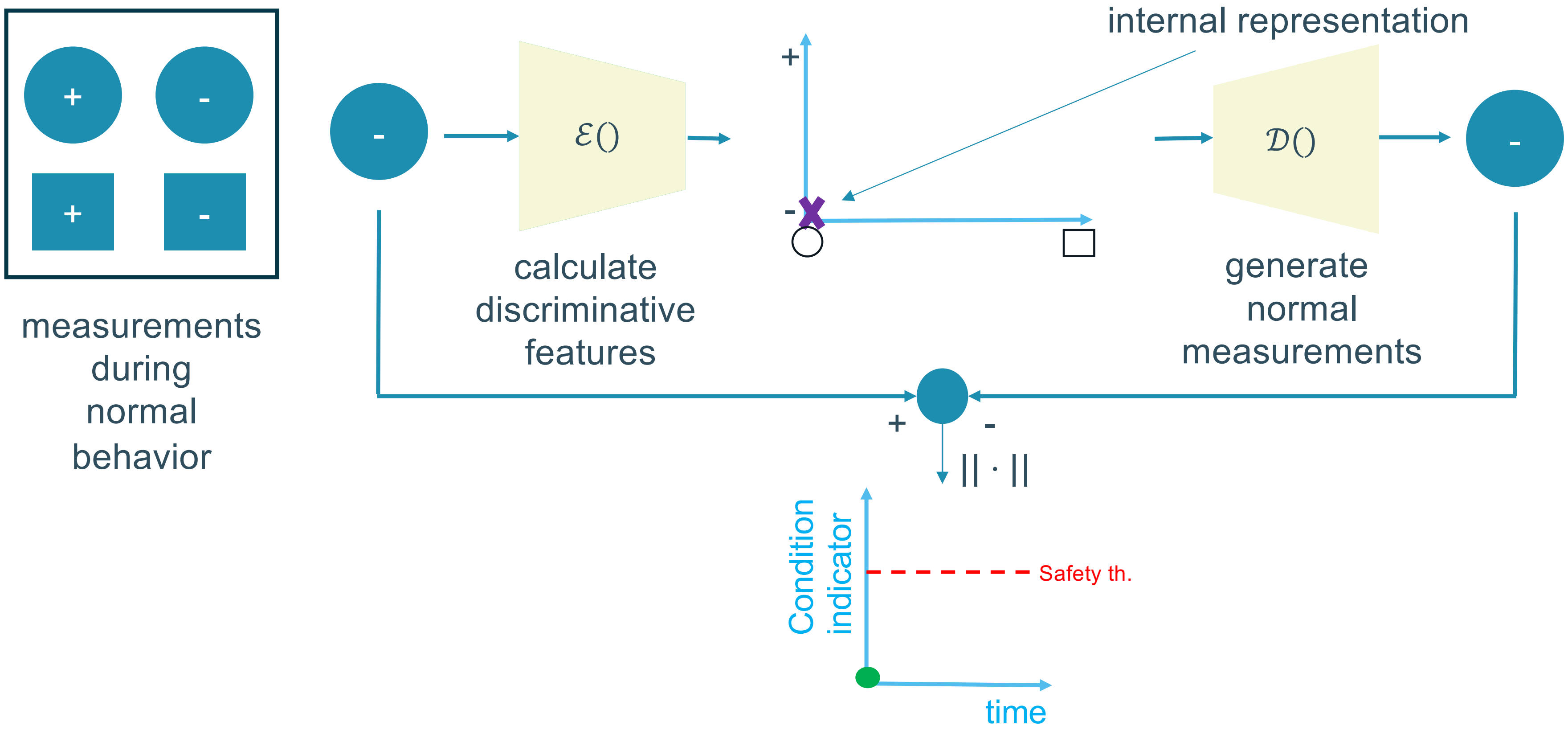

Use-case: condition monitoring

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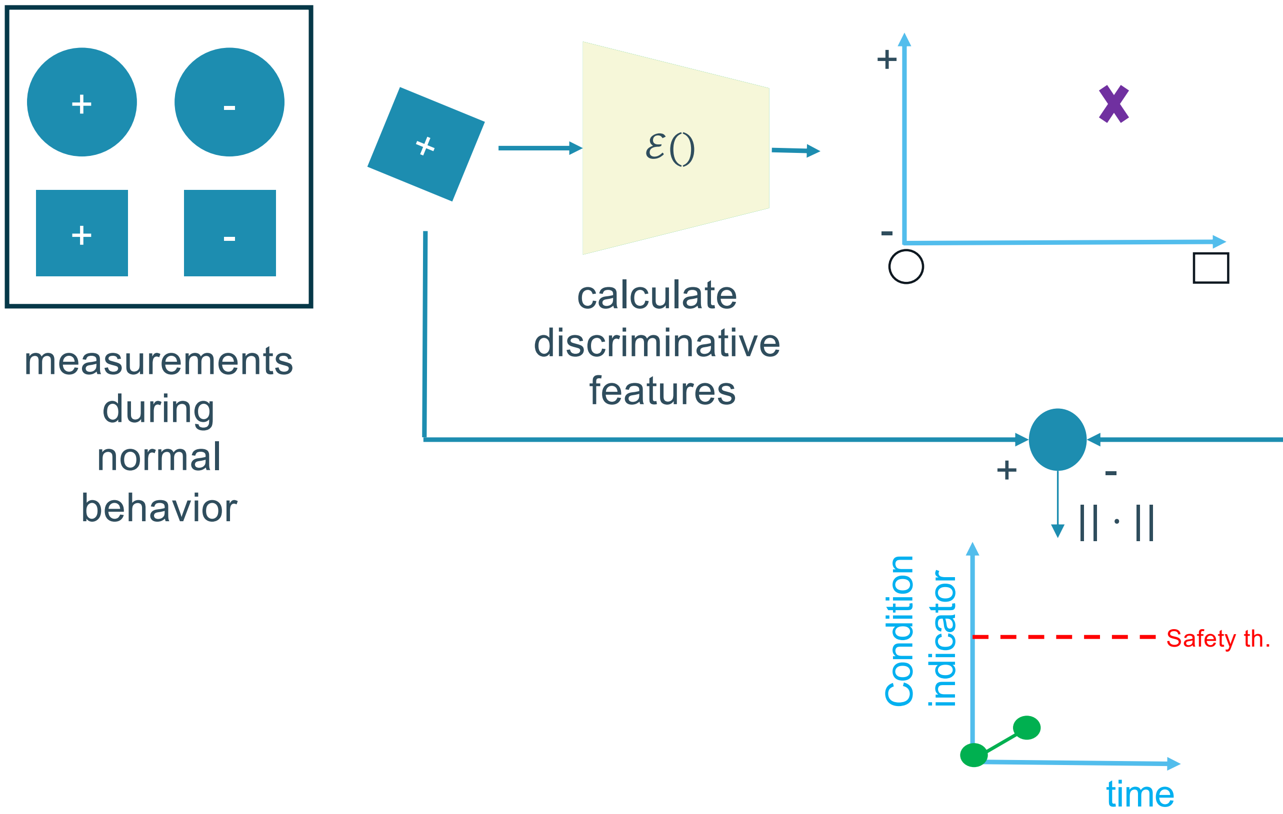

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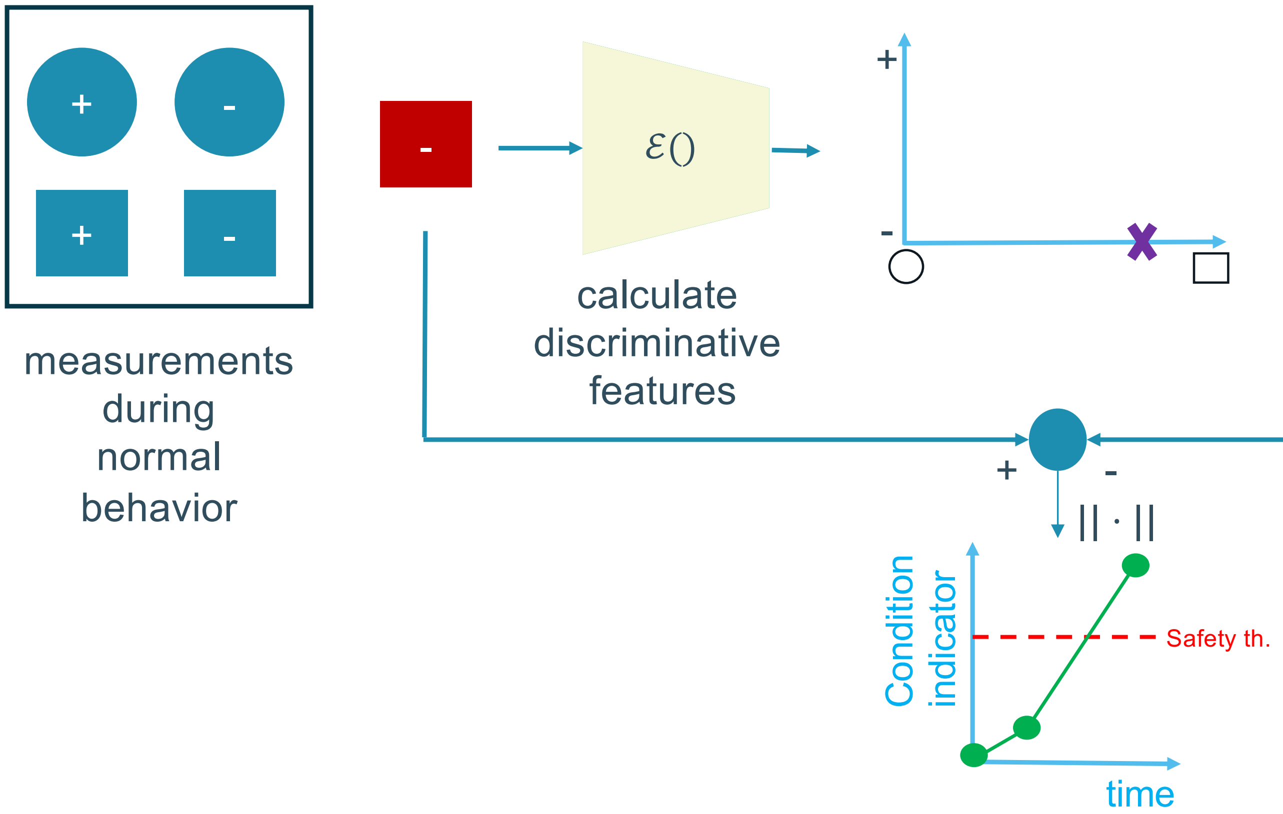

Use-case: condition monitoring

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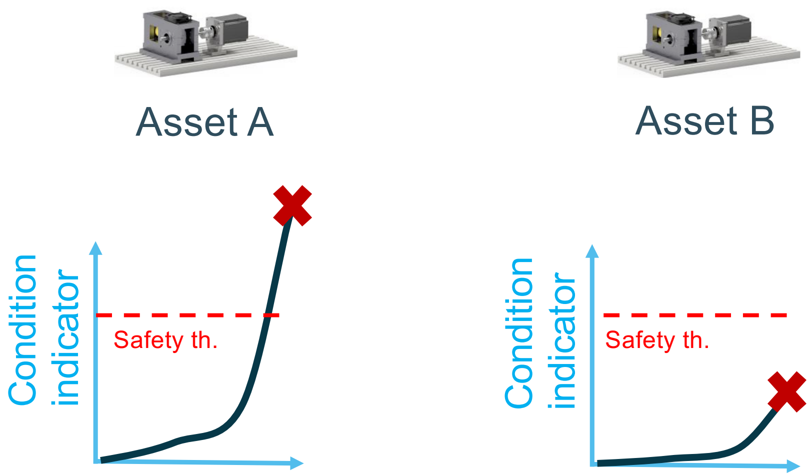
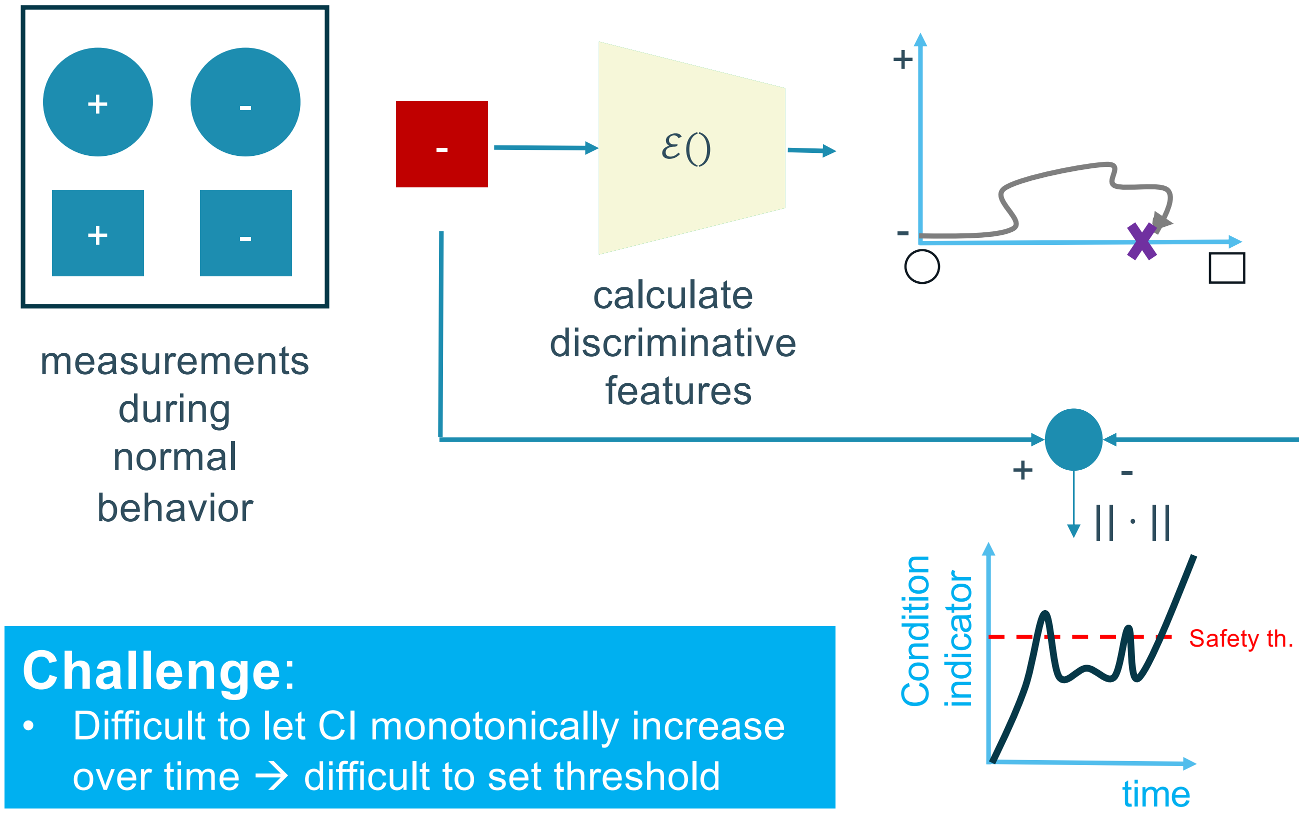


Challenges:
- CI range depends on machine
  → difficult to set threshold

Use-case: condition monitoring

Baseline: data-driven based condition indicator

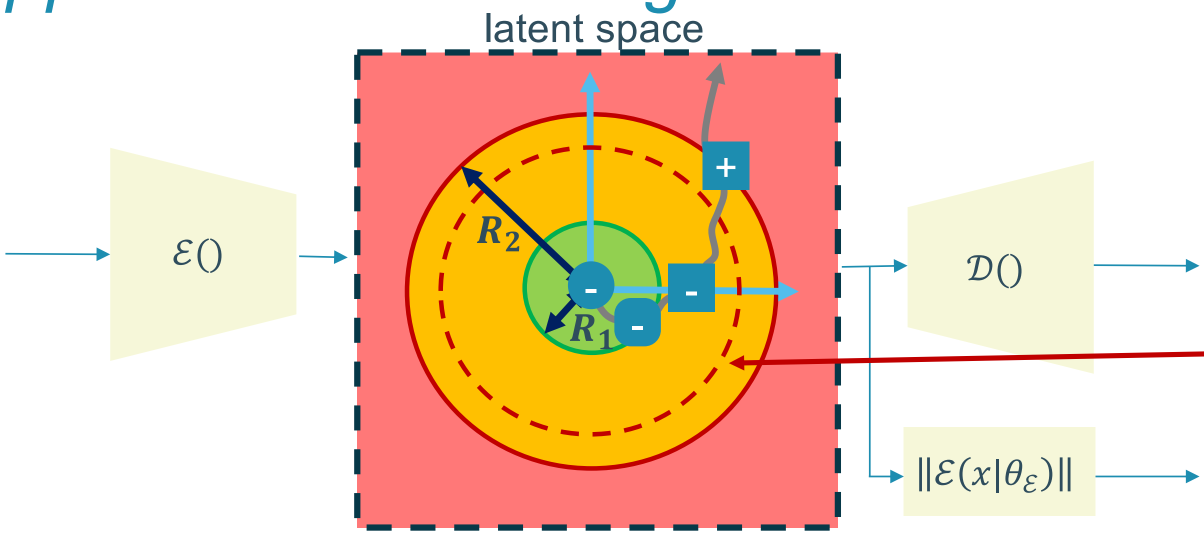


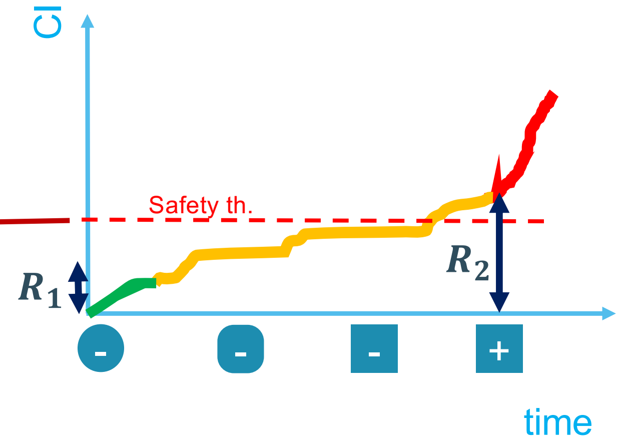
Challenge:

- Difficult to let CI monotonically increase over time → difficult to set threshold

Use-case: condition monitoring

Approach: constraint guided DL CI estimation





Optimisation problem:

`Minimize` *`reconstruction error`*

`Subject to` *`structure constraints`*

deep learning

deep learning
&
constraint satisfaction
→ Use CCGD

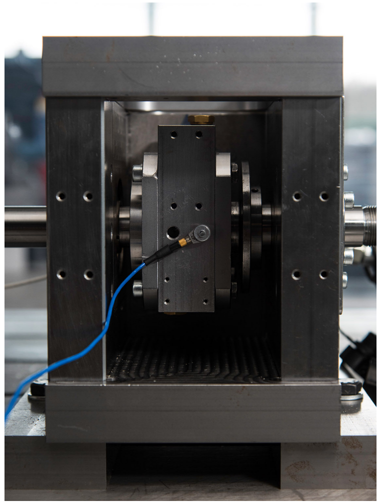
M. Meire et al., "Constraint Guided AutoEncoders for Joint Optimization of Condition Indicator Estimation and Anomaly Detection in Machine Condition Monitoring, submitted to machine learning", 2024.

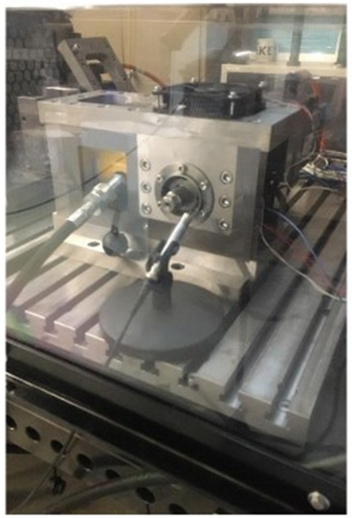
Use-case: condition monitoring

Constraint guided DL CI estimation: snapshot results

Vibration based bearing monitoring

Sound based bearing monitoring

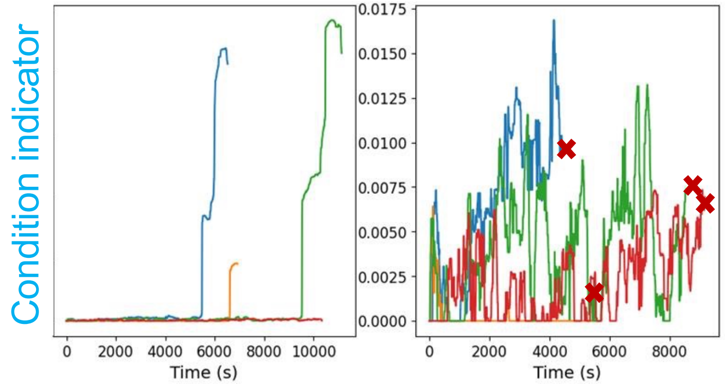




Use-case: condition monitoring

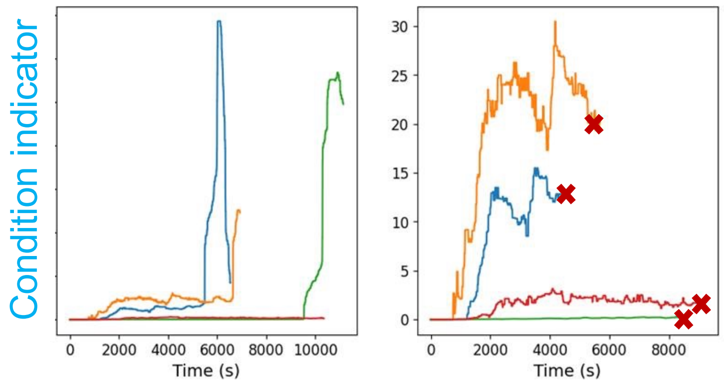
Constraint guided DL CI estimation: snapshot results

BPFI



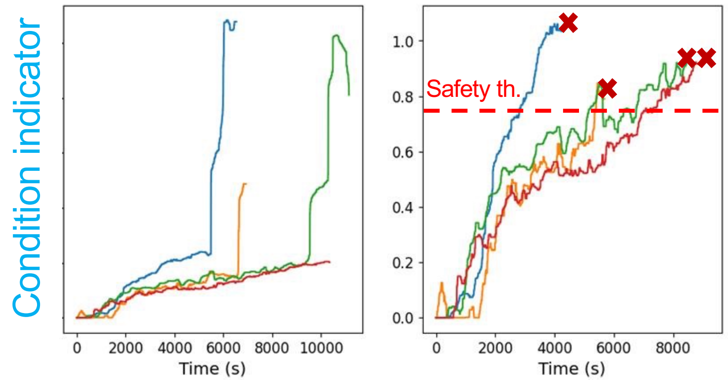
Handcrafted

AE-DSVDD



Data-driven alternative

MCGAE



Proposed

Note: evaluation on test data from runs not used in training

M. Meire et al., "Constraint Guided AutoEncoders for Joint Optimization of Condition Indicator Estimation and Anomaly Detection in Machine Condition Monitoring, submitted to machine learning", 2024.

Conclusion

- Constraint guided DL enables to learn powerful CI estimators from data for predictive maintenance without much engineering effort

- Adding structure to DL model via constraints results in:
  - a CI estimator with better generalisation properties
  - allowing a fixed, asset independent, safety treshold to be set