Physics-Informed Machine Learning for Predictive Maintenance

Applied Use-Cases

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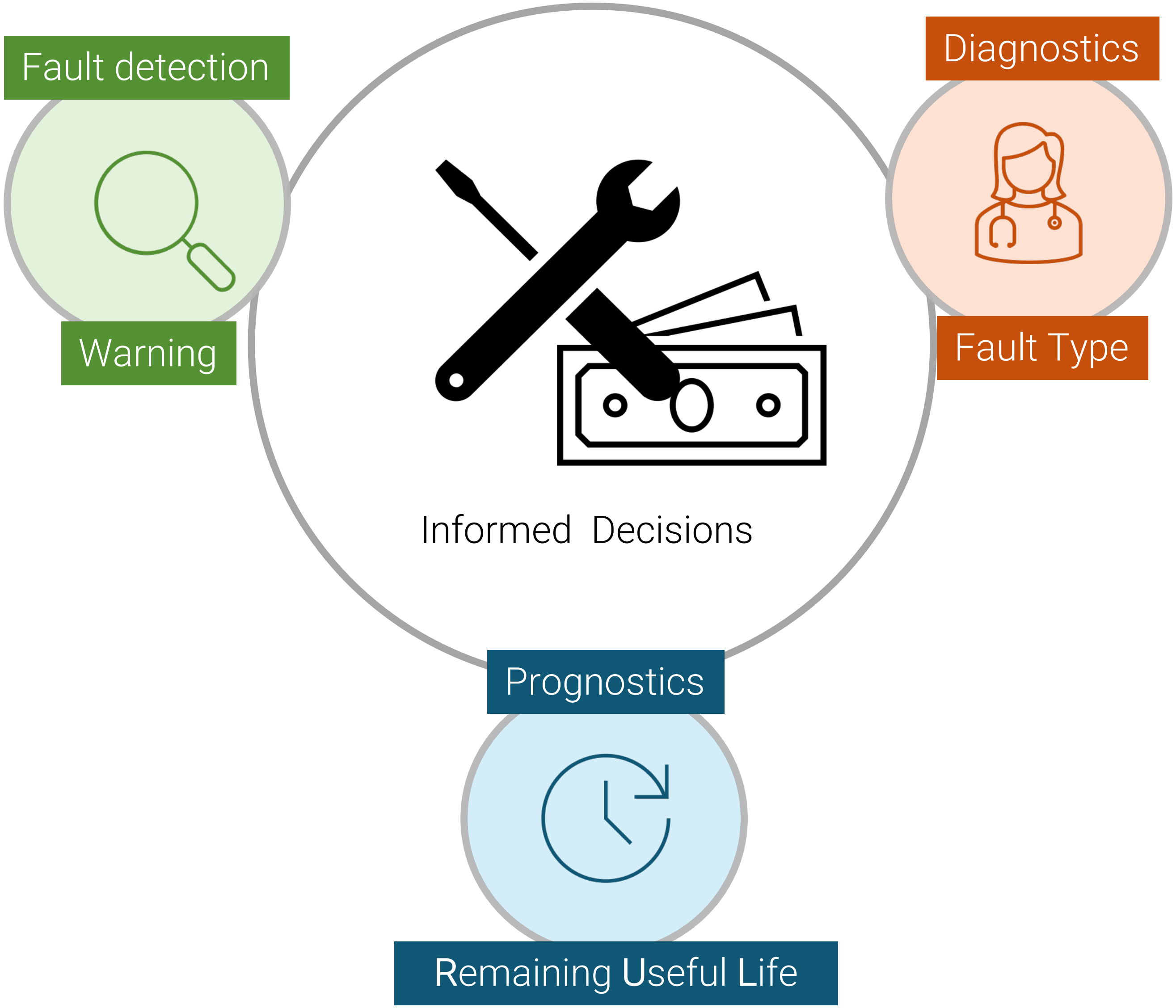
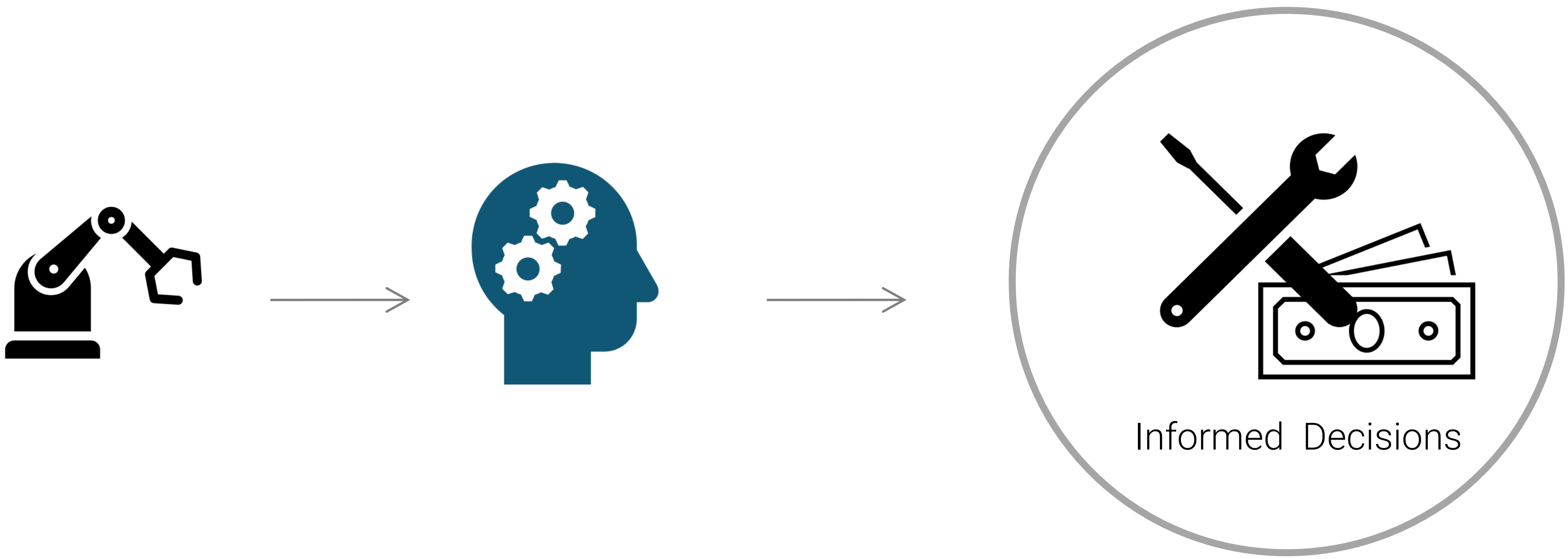
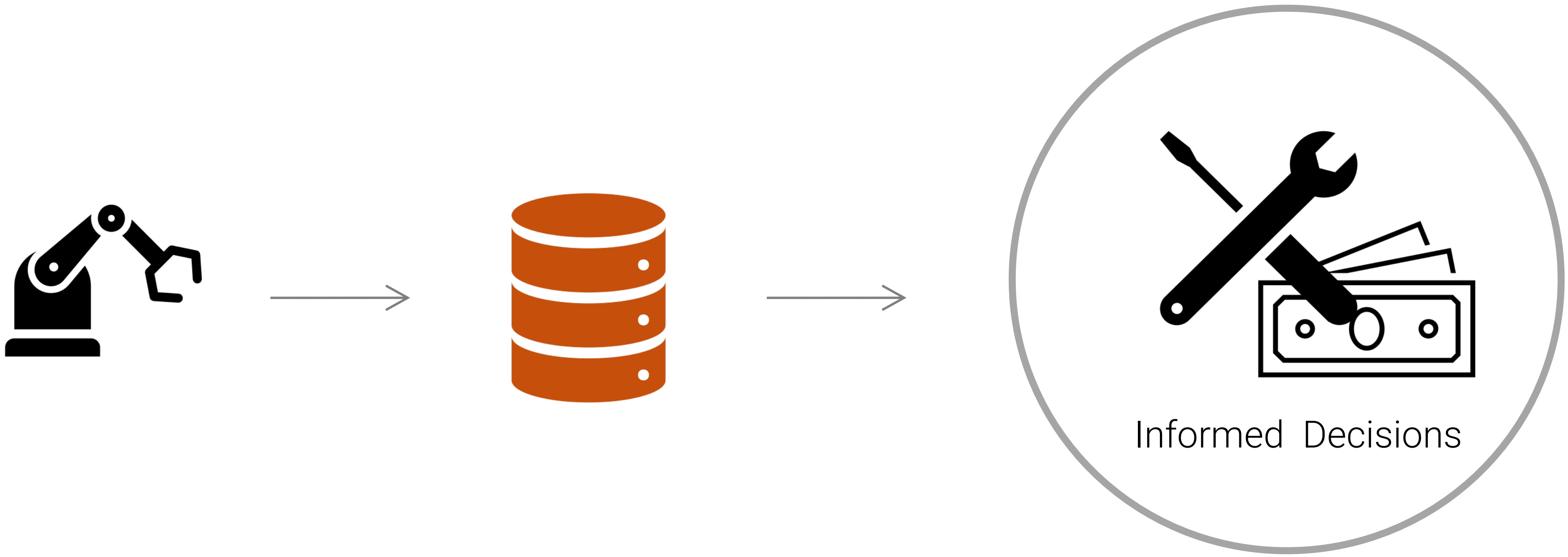
Intelligent Operation and Maintenance Decisions



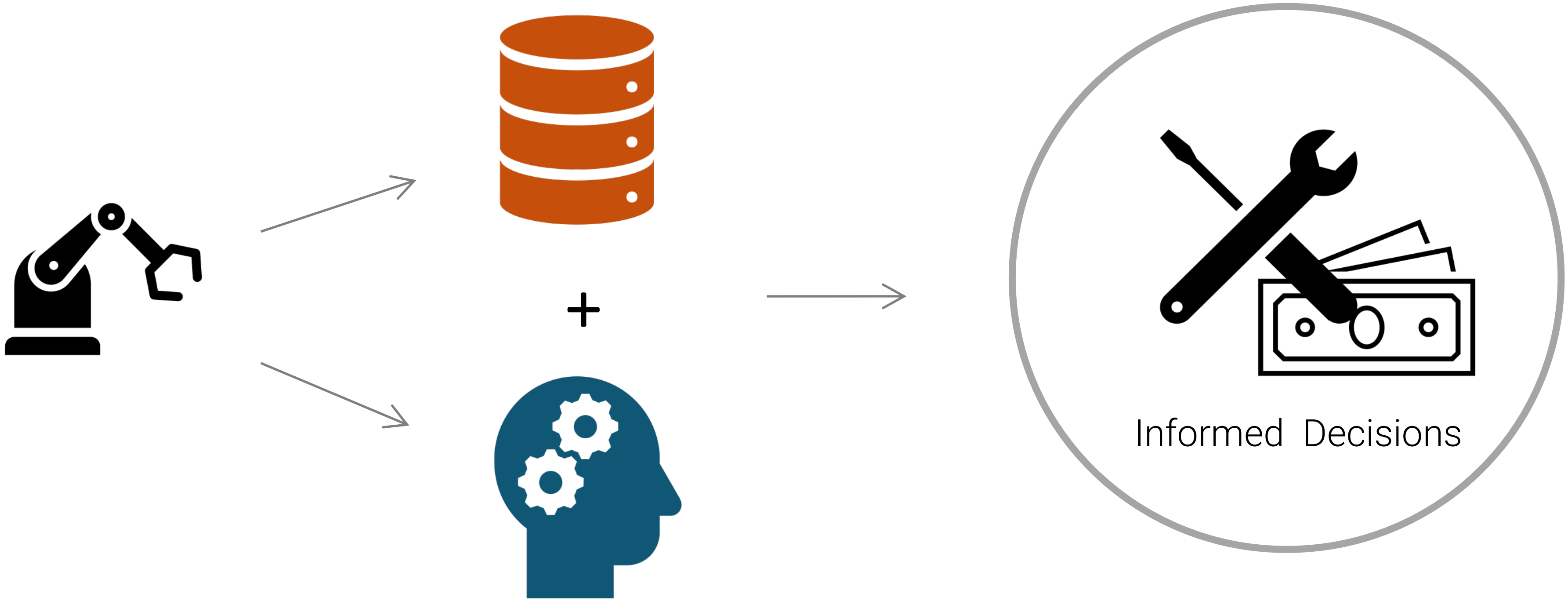
Intelligent Operation and Maintenance Decisions



Intelligent Operation and Maintenance Decisions

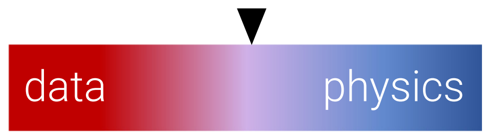


Intelligent Operation and Maintenance Decisions



Physics-Informed Machine Learning

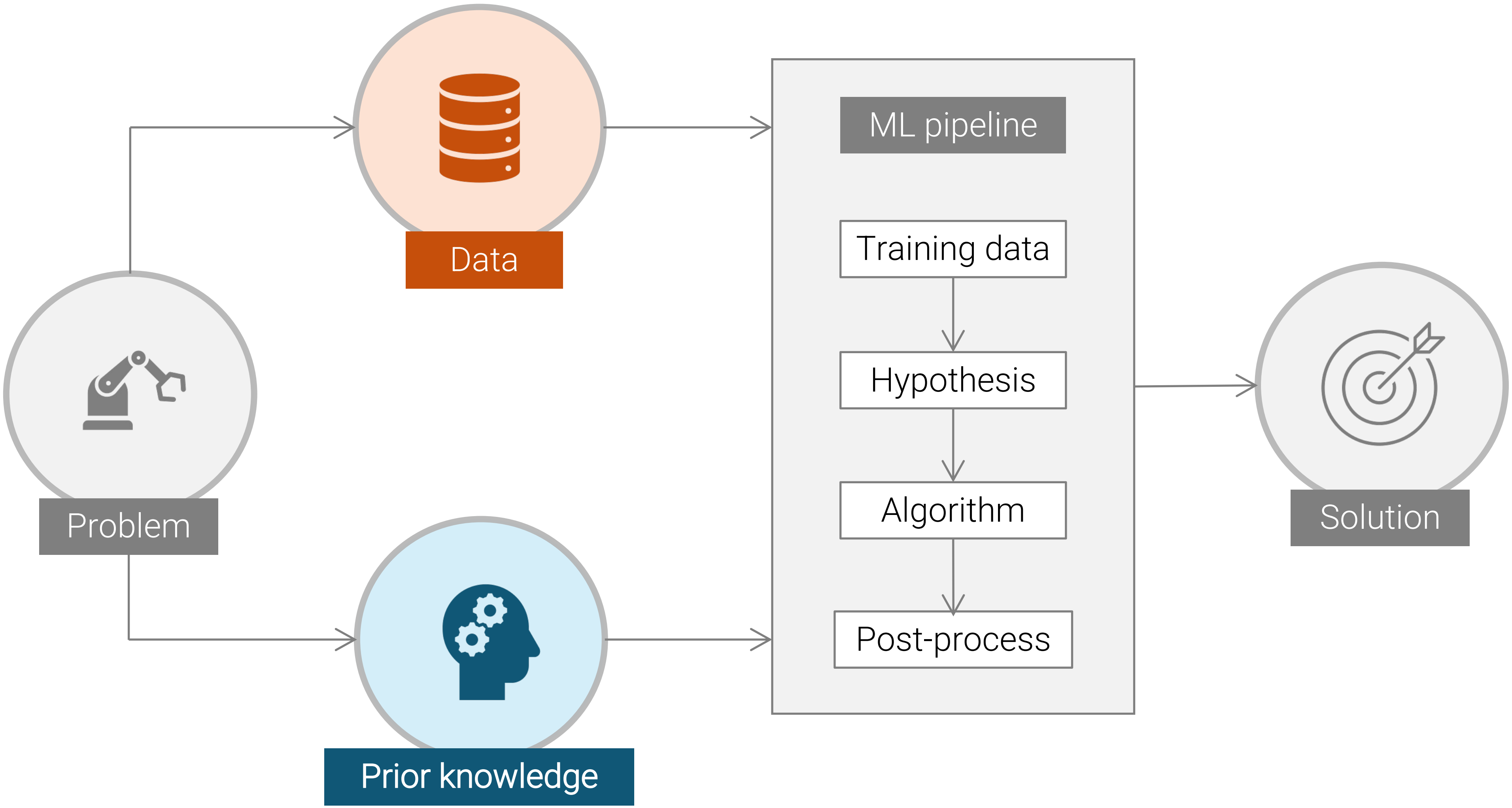
Need less labeled data



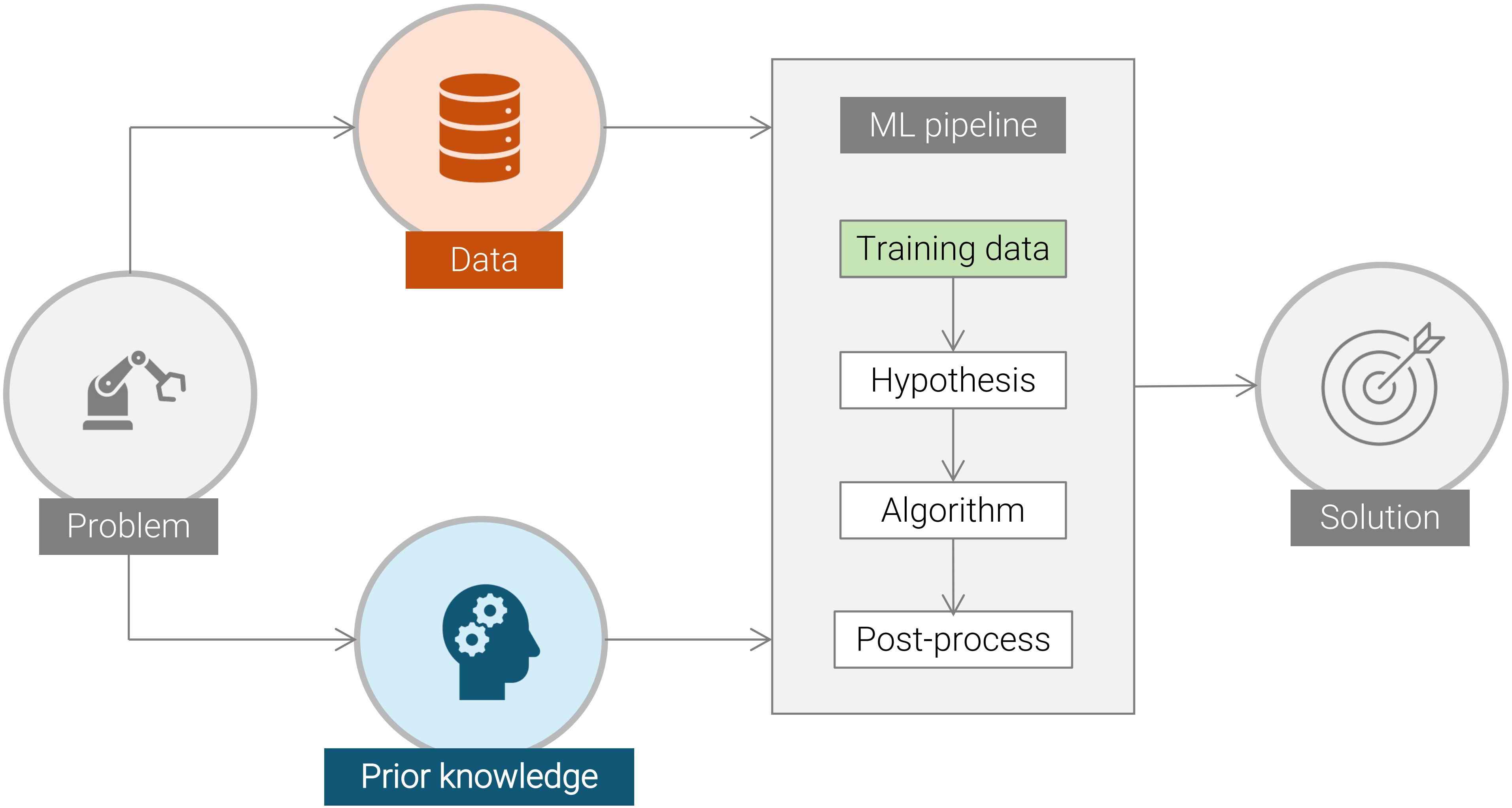
Interpretability

Domain adaptation of existing physical models

Physics-Informed Machine Learning



Physics-Informed Machine Learning



Use Case I : Tracker Faults in Solar Power Plants

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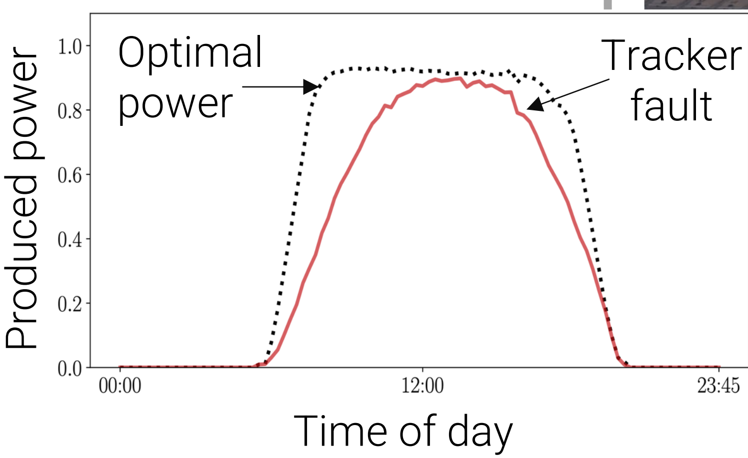
A Siemens and AES Company

Fault detection

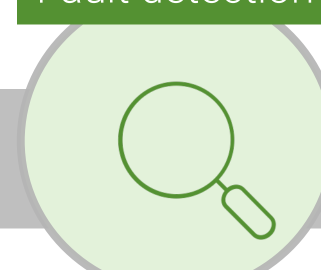
Challenge: no labeled faults

Warning

Use Case I : Tracker Faults in Solar Power Plants



Fault detection



Warning

Challenge: no labeled faults

Fault simulator using data + physics

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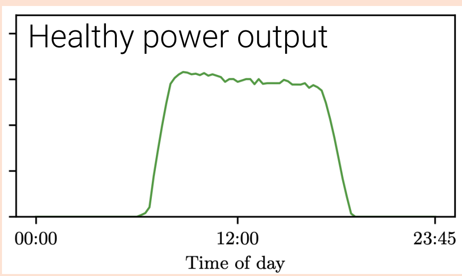
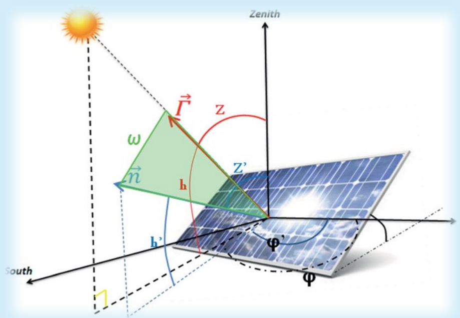
Operational data

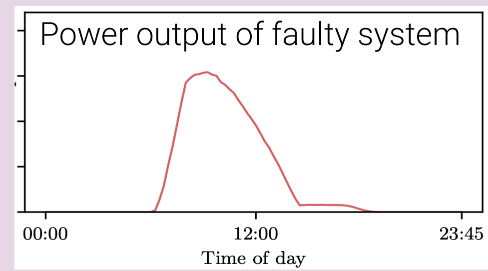


+

Physical model

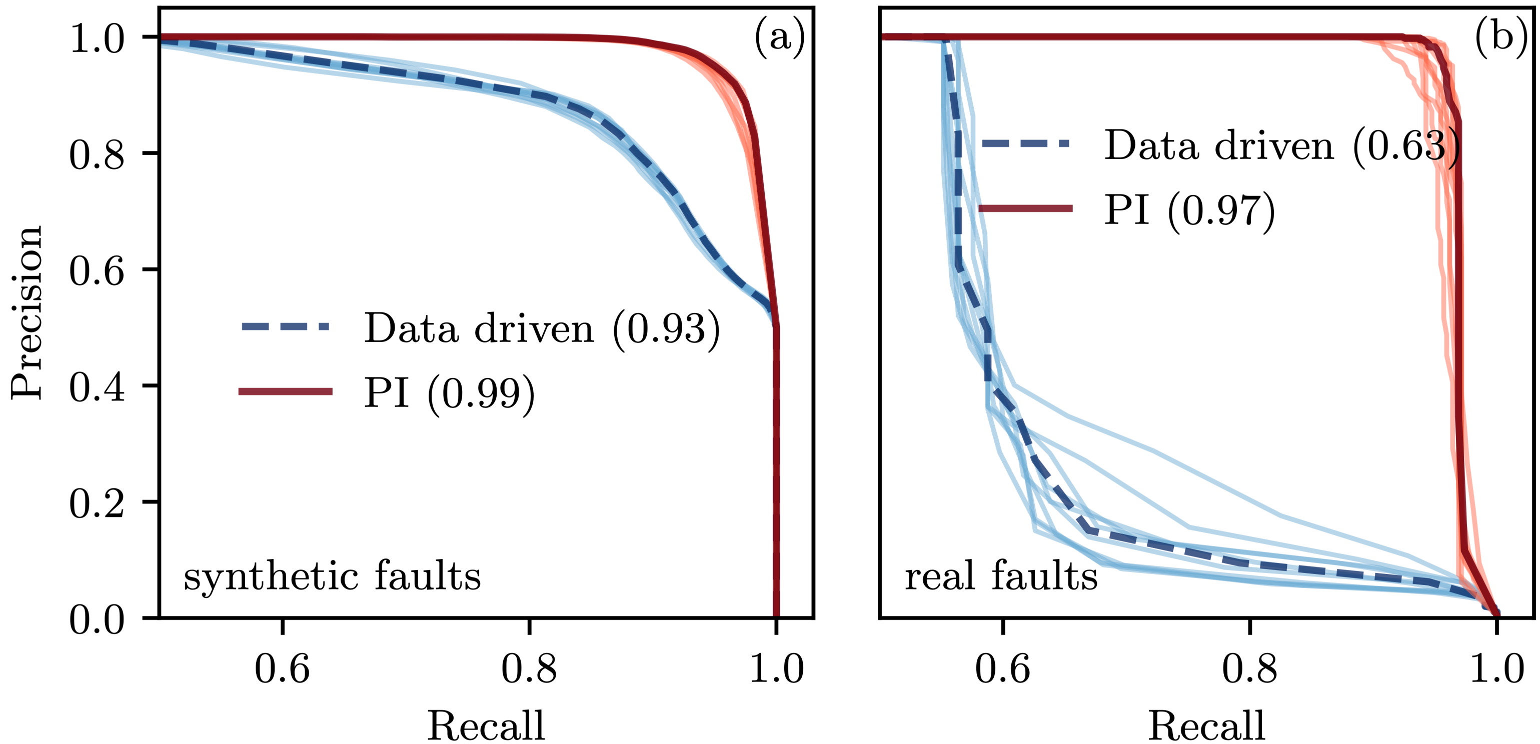


Synthetic Faults



Train CNN classifier

Results: Precision-Recall of Fault Detection



PI deep learning (DL) is superior to DL alone

Zgraggen, Jannik, et al. "Physics informed deep learning for tracker fault detection in solar power plants" (2022).

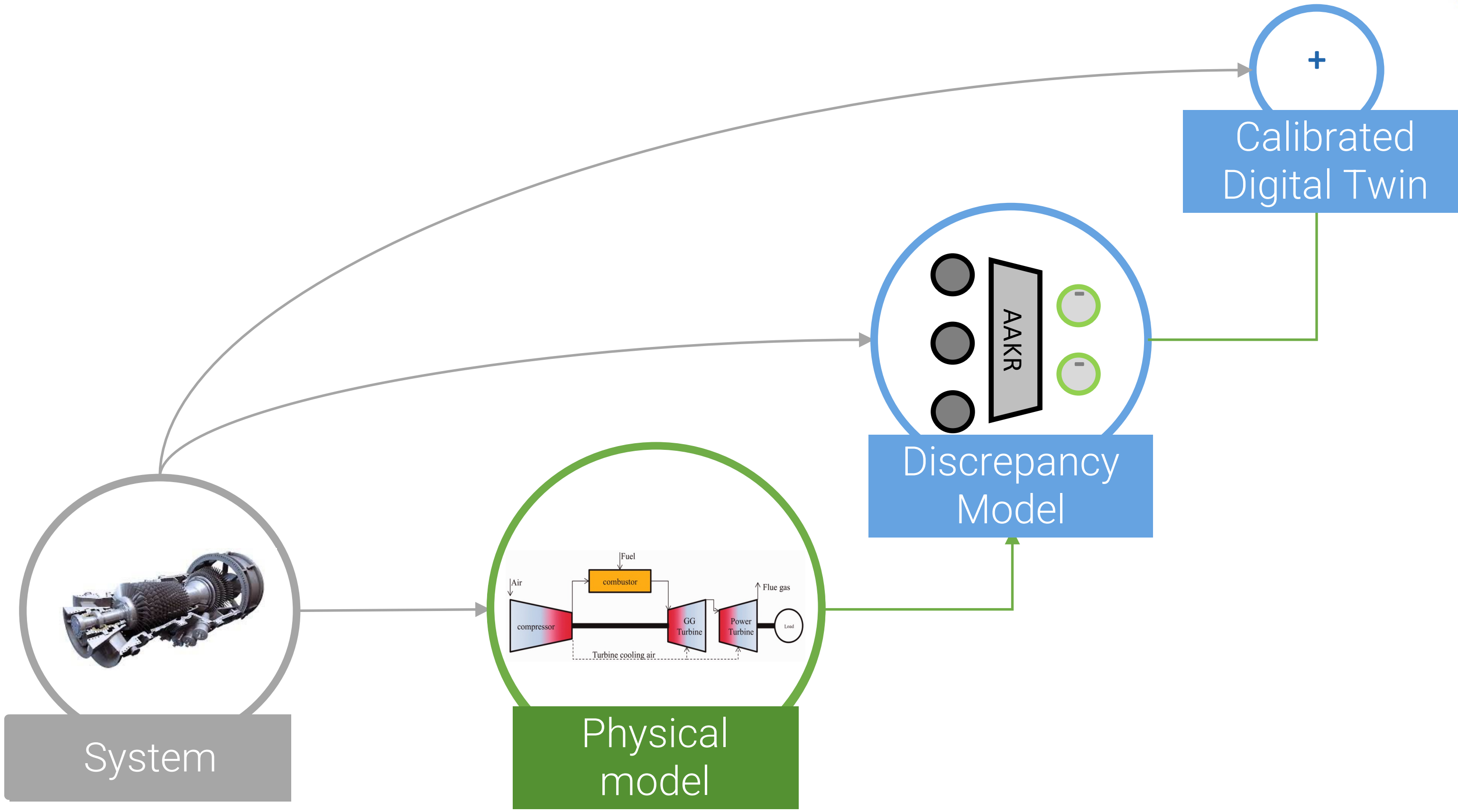
Use Case II : Fault Diagnostics of Gas Turbines

Diagnostics

Fault Type

Challenge: physical model does not cover unit-to-unit variability

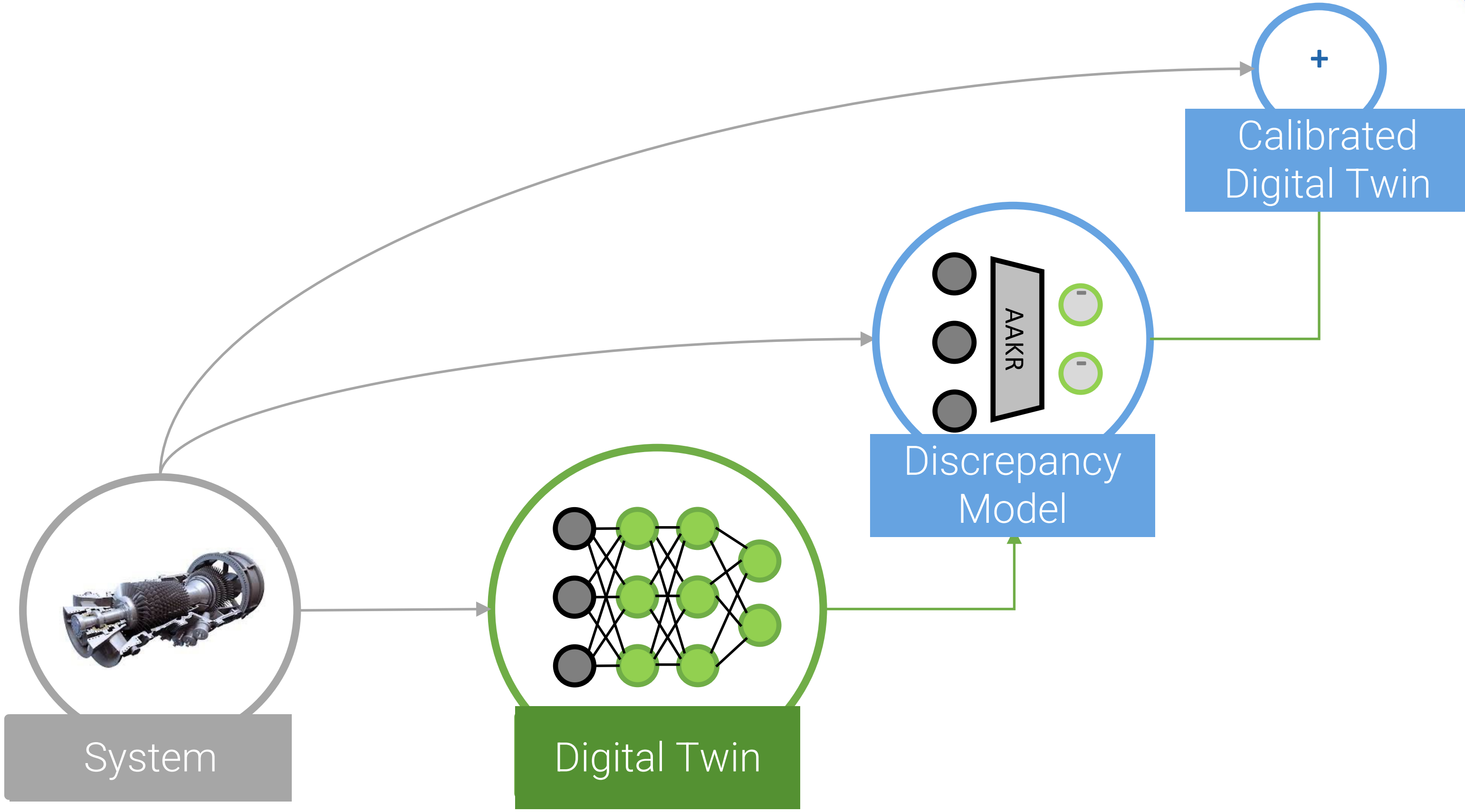
Transfer Learning for Digital Twins



Accurate predictions for a specific unit, also with little data.

Image courtesy: Sanaye, Sepehr et al. (2020)

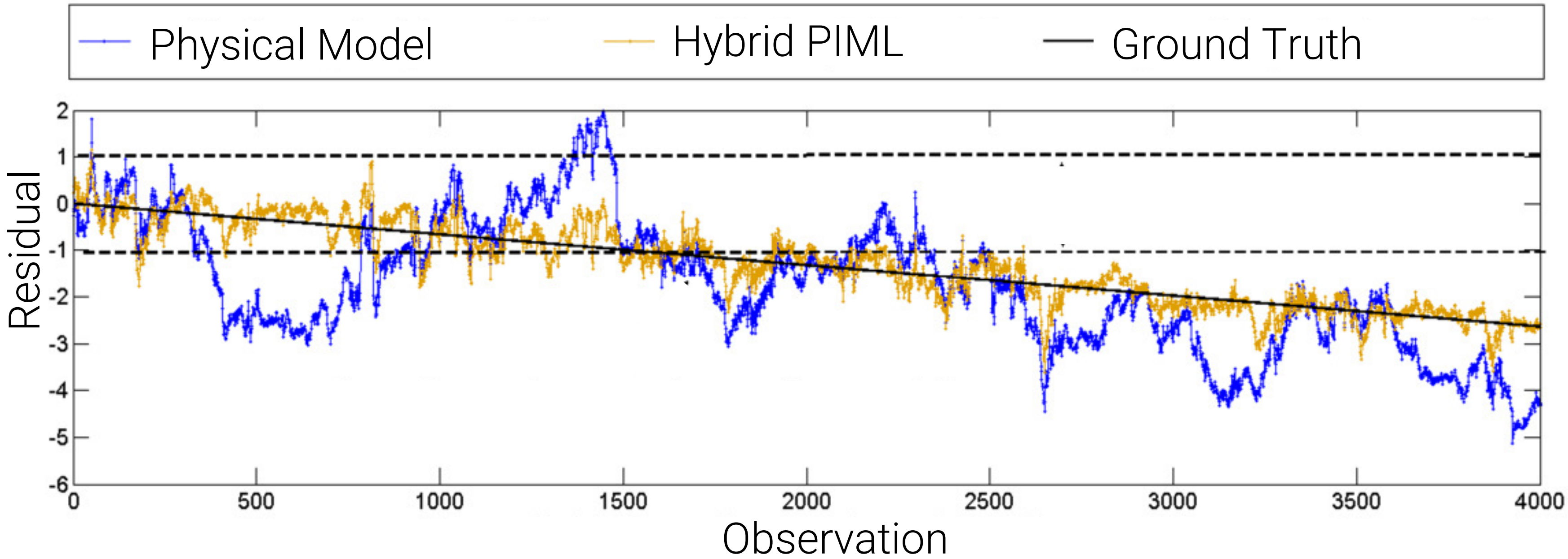
Transfer Learning for Digital Twins



Accurate predictions for a specific unit, also with little data.

Image courtesy: Sanaye, Sepehr et al. (2020)

Results: Degradation Trending and Fault diagnosis

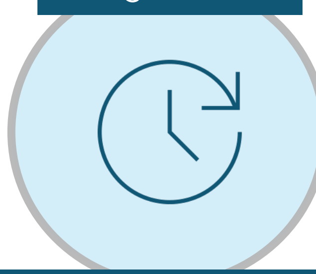


Palmé Thomas et al. "Hybrid Modeling of Heavy Duty Gas turbines for On-line Performance Monitoring" (2014).

Hybrid approach is superior to physical model

Use Case III : Fault Prognostics for Aircraft Engines

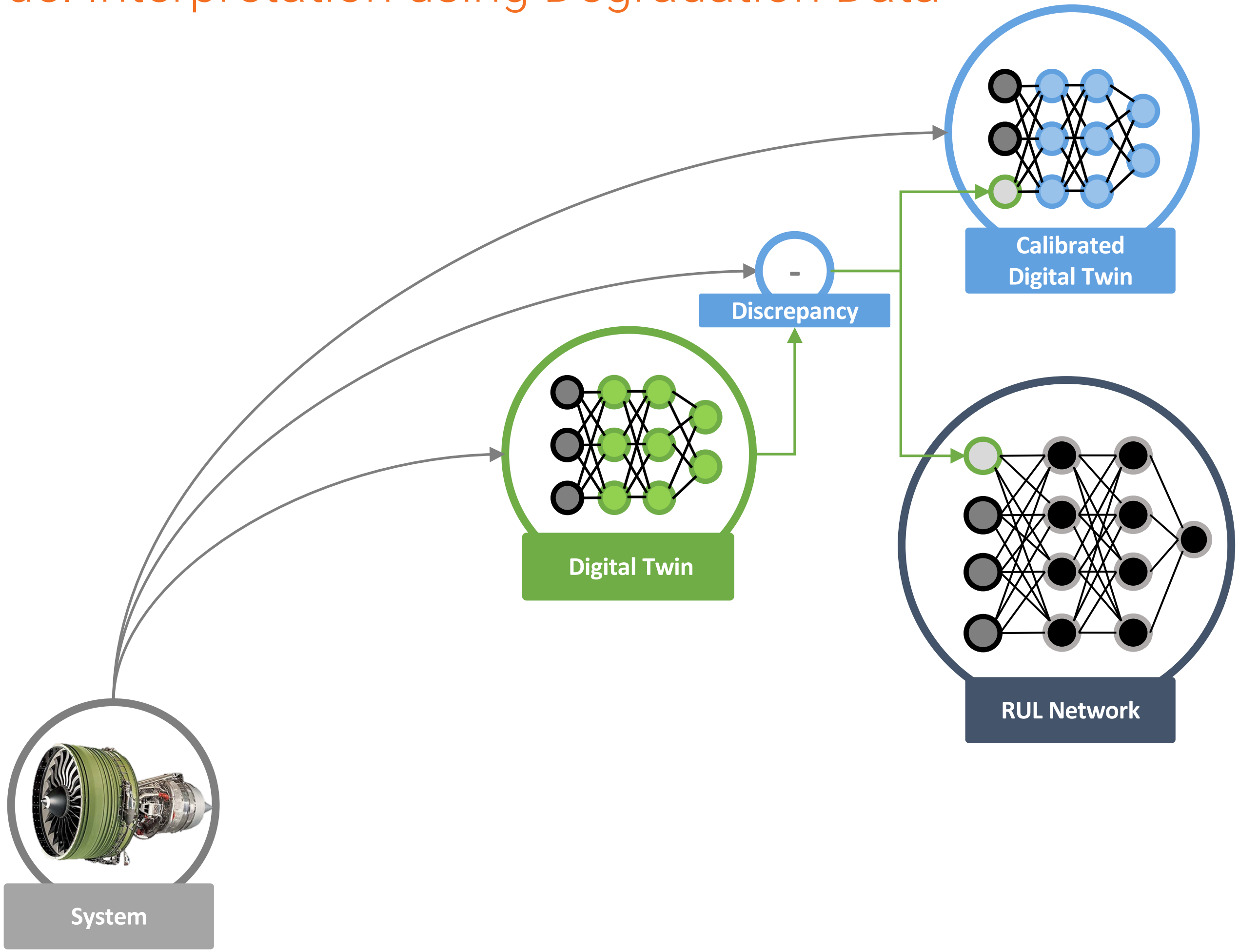
Prognostics



Remaining Useful Life

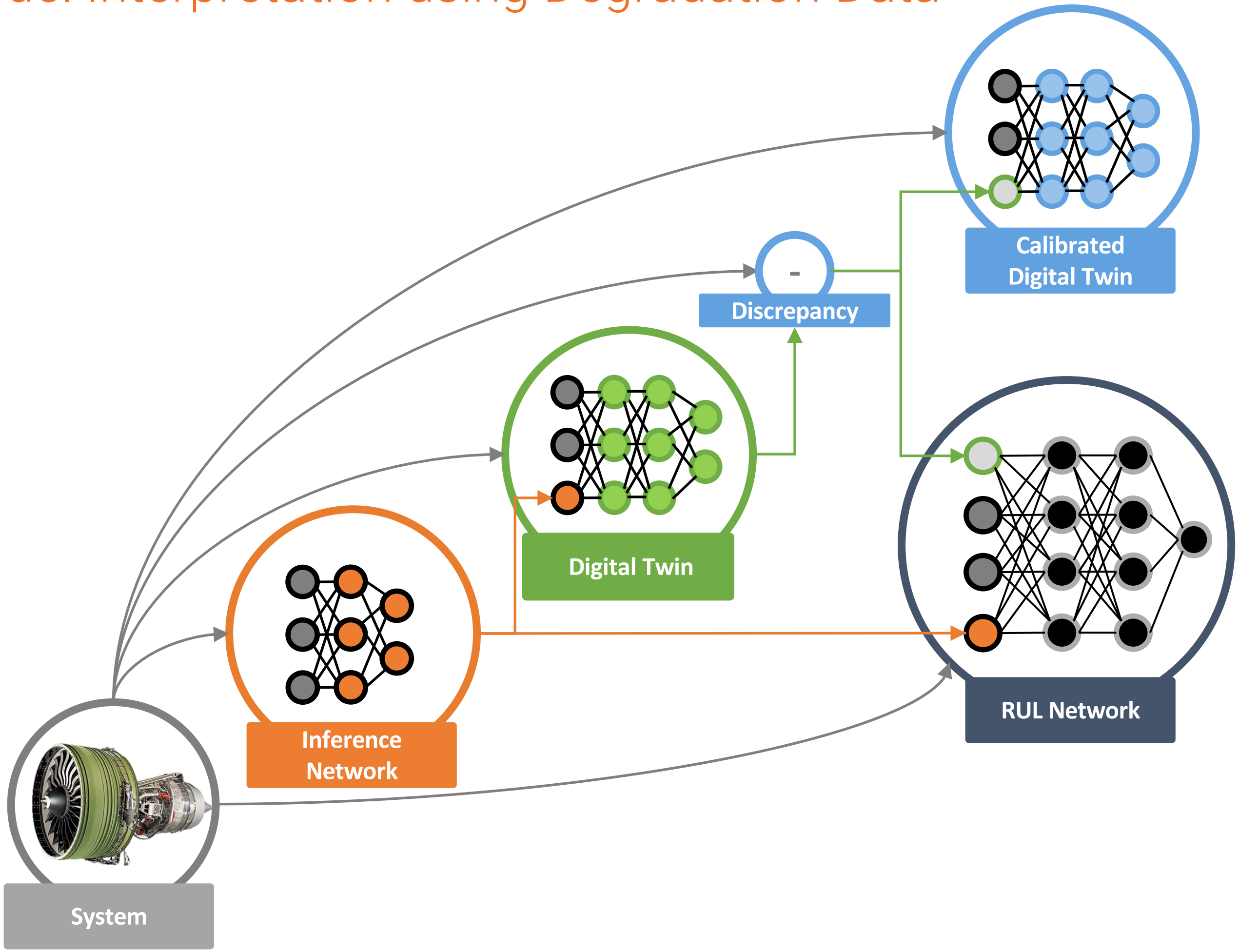
Challenge: Interpretable RUL prediction with sparse data

Performance Model Interpretation using Degradation Data



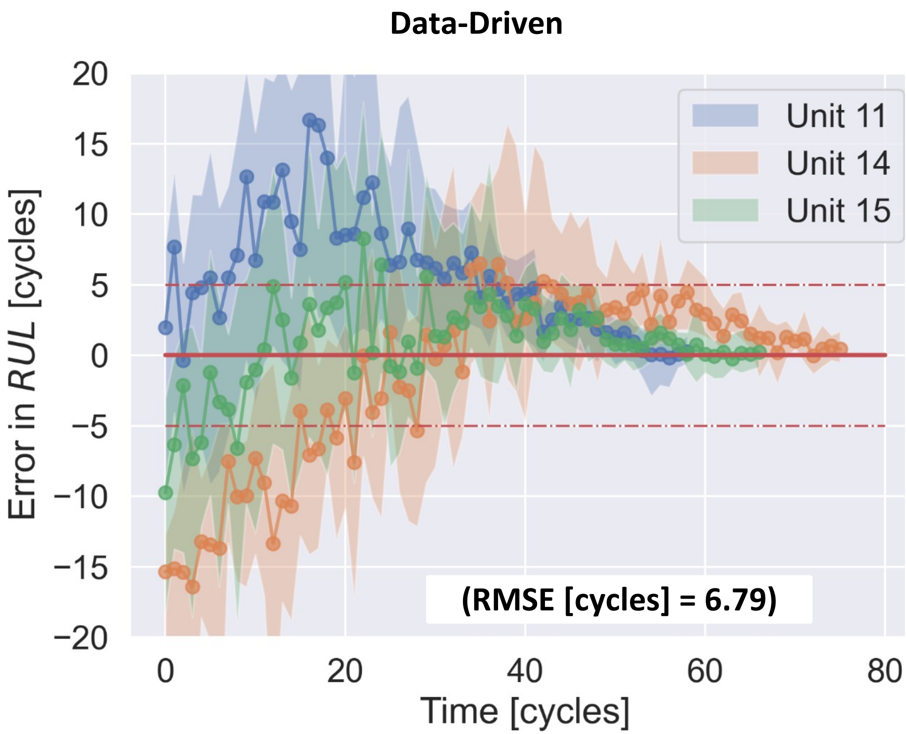
Interpretable degradation prognostics with little data

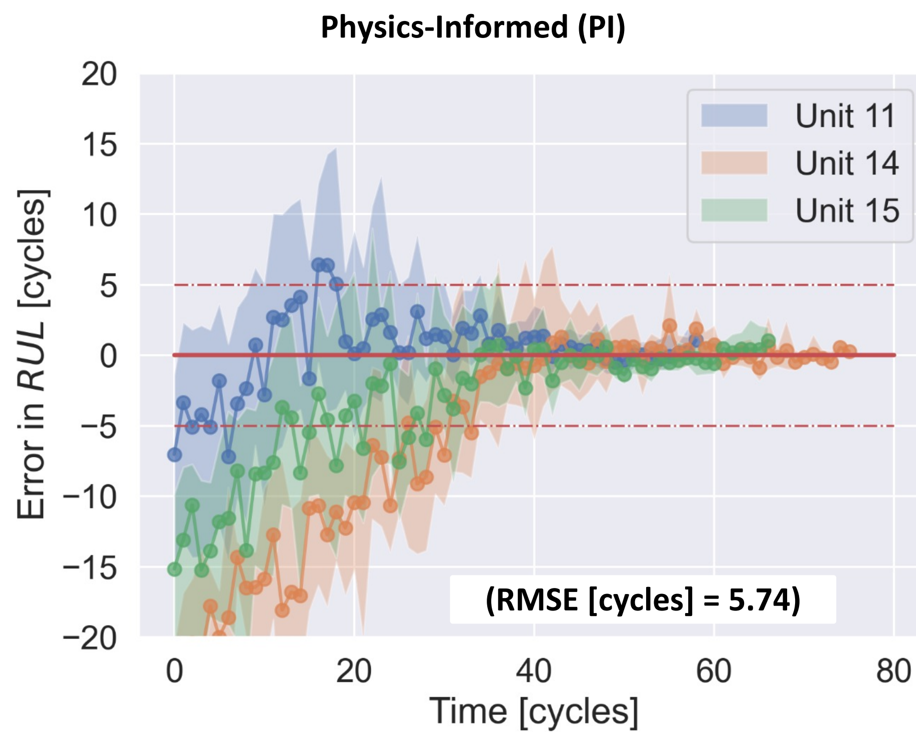
Performance Model Interpretation using Degradation Data



Interpretable degradation prognostics with little data

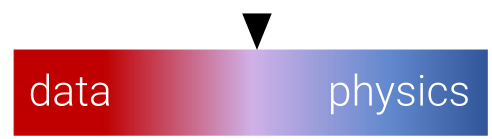
Results: Robust RUL Prediction with little data



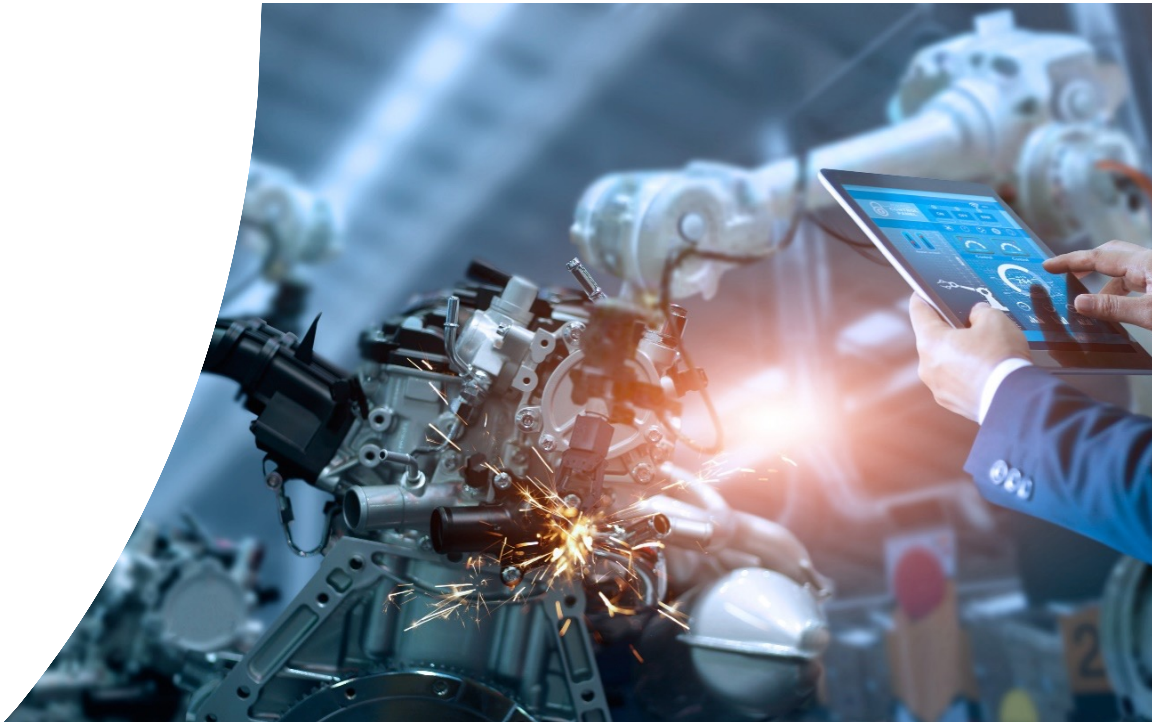


Hybrid approach is superior to data-driven model

Summary

Solar power plants	Gas turbines	Aircraft engines
		
Synthetic fault generation from healthy field data	Transfer learning: data-driven calibration of a digital twin	Performance model interpretation using degradation data
Anomaly detection	•Degradation trending •Fault localization	RUL prediction with diagnostics
Early and accurate deployment with **little field data** **Interpretability & extension** **Acceptance** of domain experts		
		

Questions?



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