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# Probabilistic Estimation of Health Indicators of Complex Systems

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## 1. Scientific Context

### Estimating the health of complex industrial systems with Digital Twins (DT)

- Utilizing sensor data to monitor industrial systems
- Probabilistic estimation of health indicators (HI)
- Combining invariant characteristics and learned information from measured data

### Considering the physics governing system operation

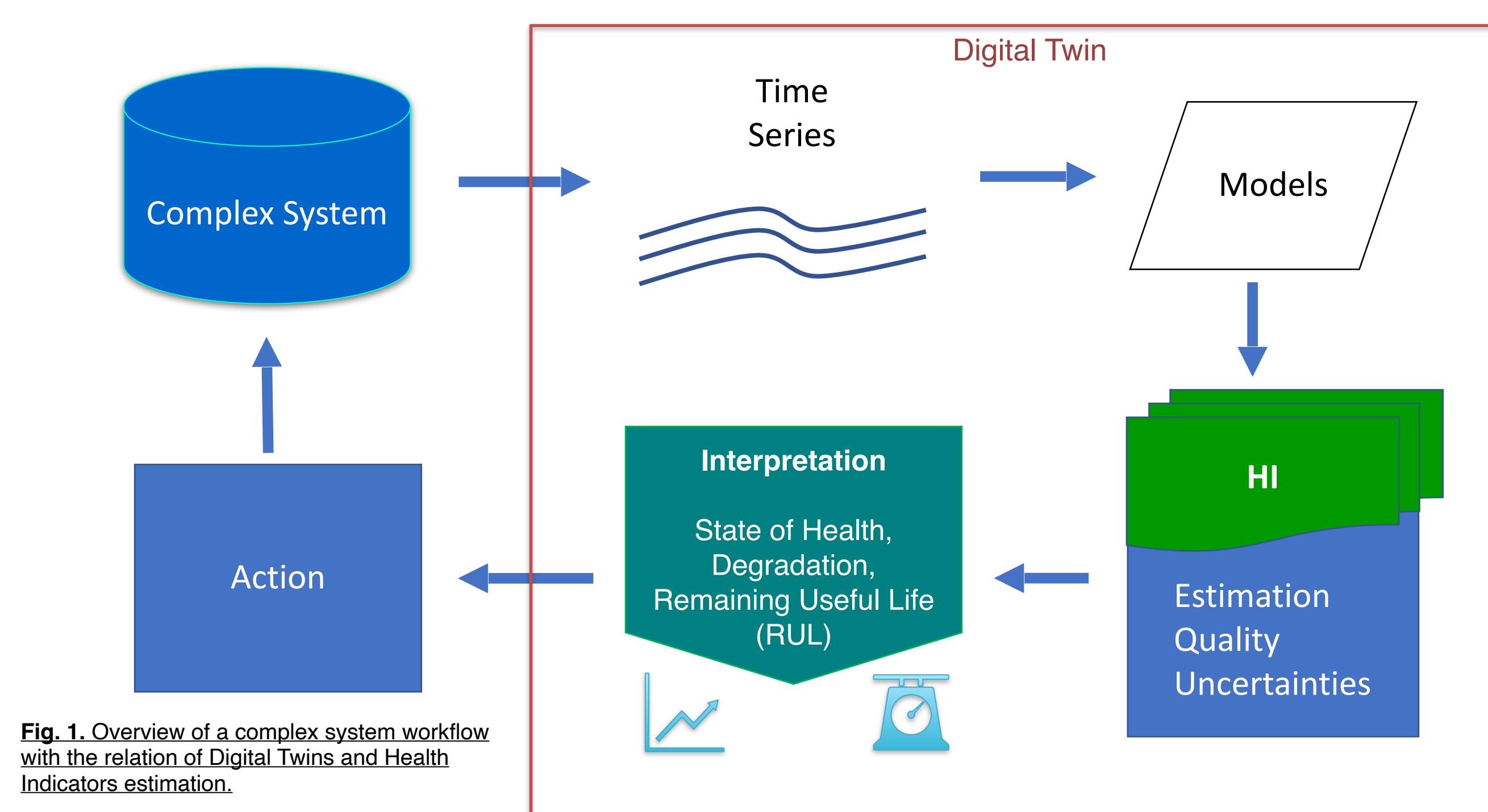


Fig. 1. Overview of a complex system workflow with the relation of Digital Twins and Health Indicators estimation.

## 2. Challenges and objectives

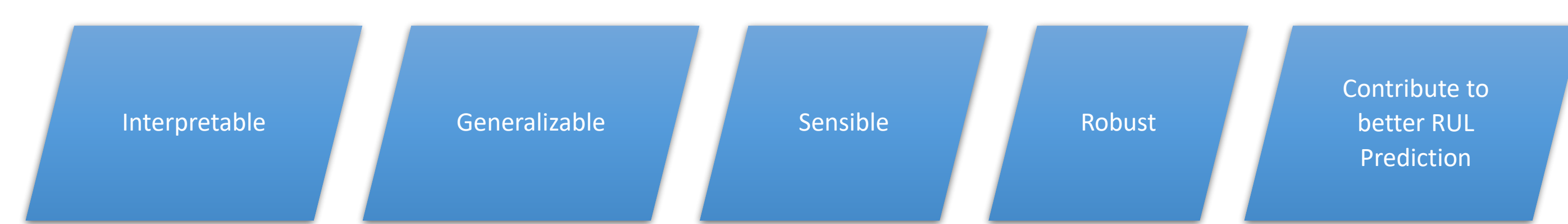
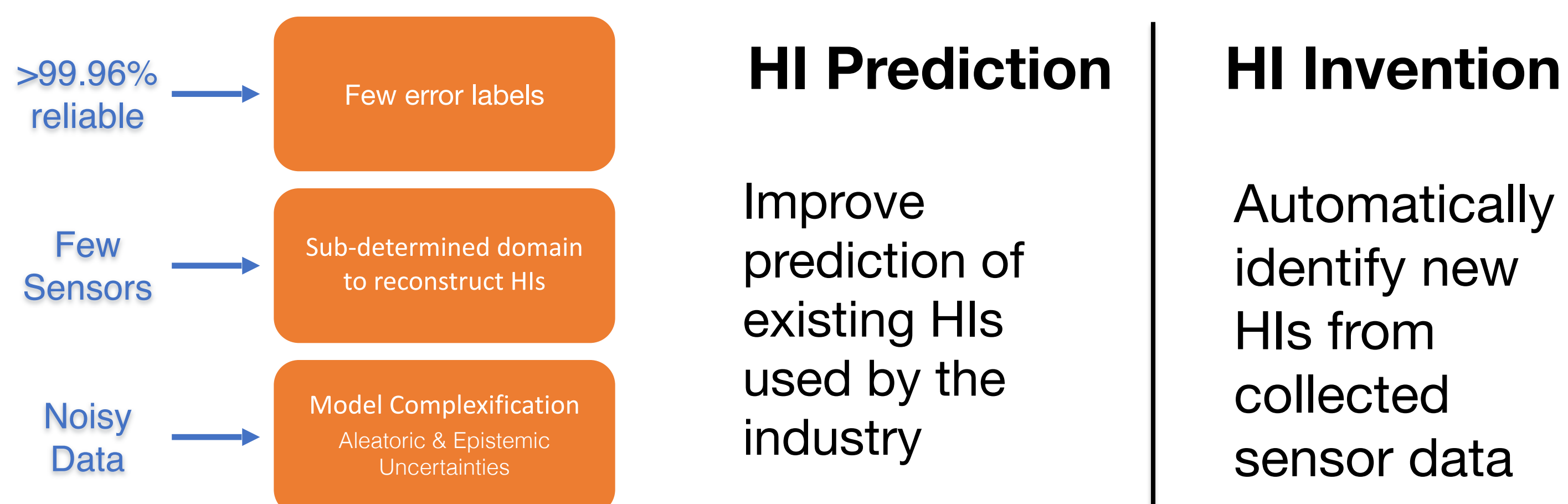


Fig. 2. Health Indicator (HI) Properties



## 3. Proposed research method

- Identify current challenges in the literature and the industry
- Explore HIs created by data-driven methods
- Propose an AI pipeline architecture to model both HIs with uncertainties: aleatoric and epistemic
- Investigate learning methods: supervised, unsupervised, reinforcement
- Incorporate physics-informed methods

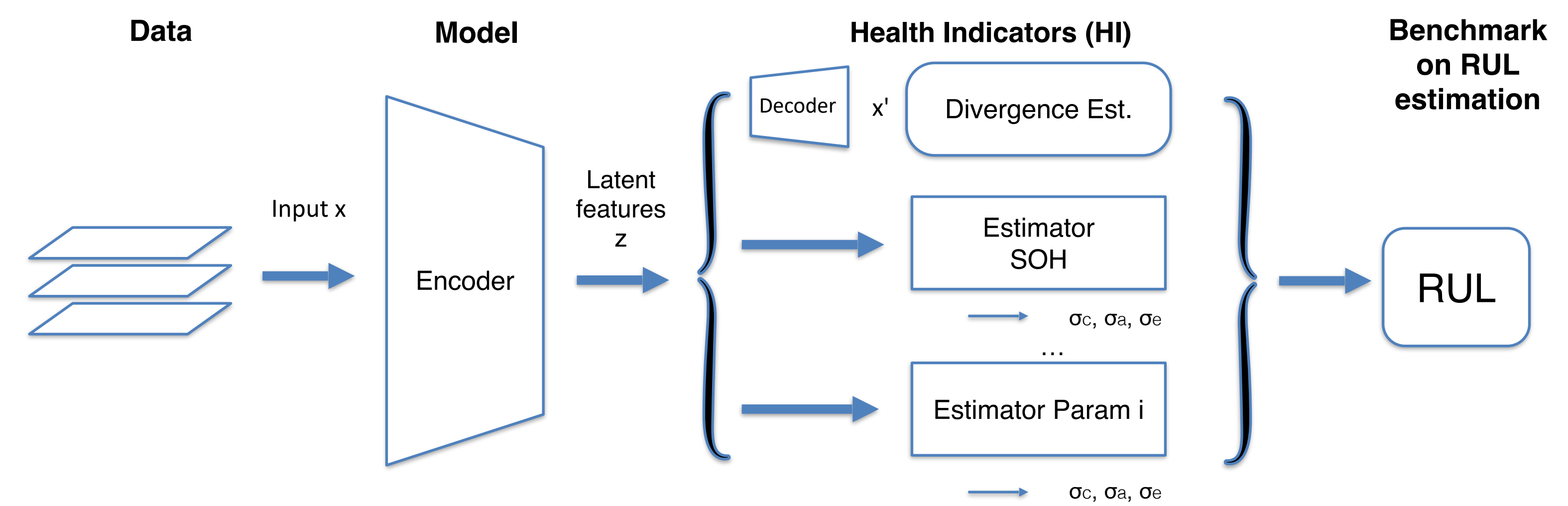
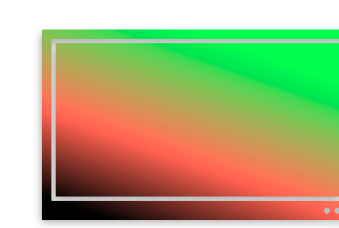
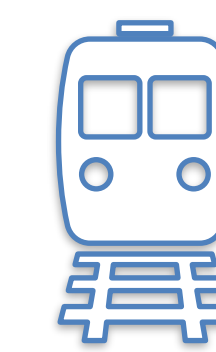


Fig. 3. Overview of the Expected Architecture

## 4. Case study



CX2 Battery Degradation & PyBaMM Simulator [9-10]



Railroad degradation



Safran Turbofan engine

- Assessing real-world applicability
- Managing intricate, real-world scenarios
- Pinpointing and mitigating uncertainty sources
- Evaluating and enhancing performance

## 5. Expected results

- Unified domain agnostic framework to predict and create HIs
- Gaussian approximation for quantification in aleatoric & epistemic uncertainties
- Benchmarked on RUL estimation
- Interpretable degradation maps

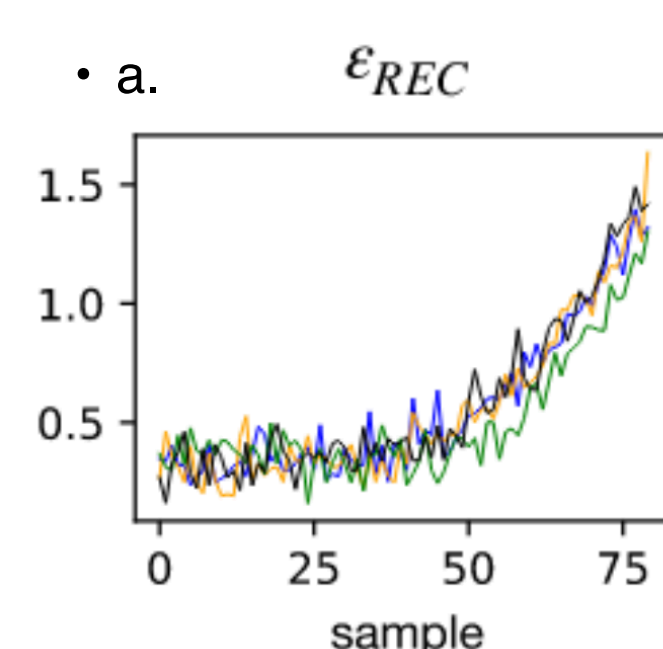


Fig. 5.a. HIs built on deep auto encoder residuals for a degradation profile belonging to FD001 dataset. [1]

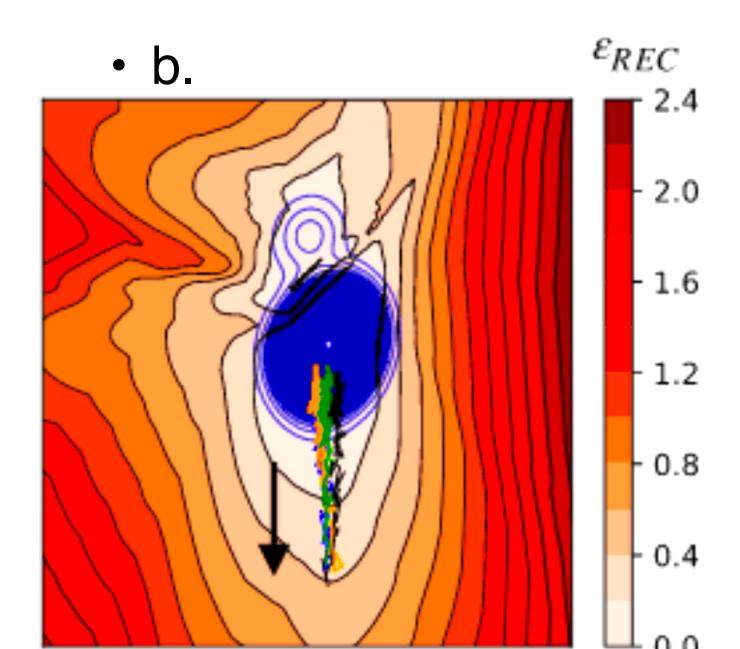


Fig. 5.b. Health Indicator representation in the latent space of the deep auto encoder for the FD001 dataset. [1]

## 6. Future work

- Physics Informed Neural Networks (PINNs)
- Domain adaptation between simulation and real datasets
- Feature selection for HI creation
- Reinforcement learning approaches

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