Engineering Risk Analysis Group

Prof. Dr Daniel Straub

MSc thesis proposal

Proper scoring rules for health indicators of engineering systems

Motivation and Objectives

Engineers and researchers utilize uncertainty quantification (UQ) to enrich classical deterministic model predictions by probabilistic statements. Domains such as weather forecasting and machine learning have a long tradition of training and also validating these probabilistic predictions based on data [1]. The key question, therefore, is: what constitutes a good probabilistic prediction? Ideally, it is both calibrated as well as sharp. Well-calibrated means that the model's predicted range of future values coincides with the observed frequencies in the long run. On the other hand, a sharp prediction is characterized by low prediction uncertainty, i.e., the predicted range for the underlying values is narrow. To balance calibration and sharpness during training, one should use a proper scoring rule [2], such as the continuous-ranked probability score (CRPS).

In prognostics for engineering systems, health indicators (HIs) are quantitative representations of a system's degradation state, derived from raw sensor measurements or processed features, and designed to evolve in a predictable manner as the system approaches failure. The quality of an HI directly impacts the ability to make accurate predictions about the future development of the system state [3], and therefore represents a crucial step in the whole prognostics and health management pipeline.

The topic of this work is the exploration of CRPS for the training of a Deep Learning based health indicator of an engineering system [see, e.g., 4]. This thesis offers a combination of method development with subsequent numerical implementations. This is an open thesis, so the objectives, as well as the workflow, can be adjusted to the student's ideas, progress, results, etc.

Methodology

The suggested workflow is as follows:

- Getting familiar with the topics of health indicators and probabilistic prediction methods
- Development of health indicator formulation based on CRPS
- Implementation of the proposed solution
- Benchmarking with commonly used health indicators on toy problems and/or real-life datasets.

Requirements

We require that the student has sufficient background/experience in:

- Probability theory and statistics, e.g., via completion of the course "Risk Analysis"
- Deep Learning, e.g., via completion of the course "Introduction to Deep Learning"

Starting date: **Flexible, as soon as possible**

Supervision

This thesis is jointly supervised by Daniel Koutas (ERA group, TUM) and Mariana Salinas Camus (iSP group, TU Delft). If you are interested in this topic, please contact Daniel Koutas (daniel.koutas@tum.de) with your transcript of records and preferred approximate starting date.

References

[1] Gneiting, T., Balabdaoui, F., Raftery, A.E., 2007. Probabilistic forecasts, calibration and sharpness. Journal of the Royal Statistical Society. Series B: Statistical Methodology 69, 243–268. https://doi.org/10.1111/j.1467-9868.2007.00587.x

[2] Murphy, K. P. (2022). *Probabilistic machine learning: an introduction*. MIT press.

[3] Coble, J., & Hines, . J. W. (2021). Identifying Optimal Prognostic Parameters from Data: A Genetic Algorithms Approach. *Annual Conference of the PHM Society*, *1*(1). Retrieved from https://www.papers.phmsociety.org/index.php/phmconf/article/view/1404

[4] Guo, L., Li, N., Jia, F., Lei, Y., & Lin, J. (2017). A recurrent neural network based health indicator for remaining useful life prediction of bearings. *Neurocomputing*, *240*, 98-109.