

Applying deep learning in metrology

An overview over some potentials and challenges

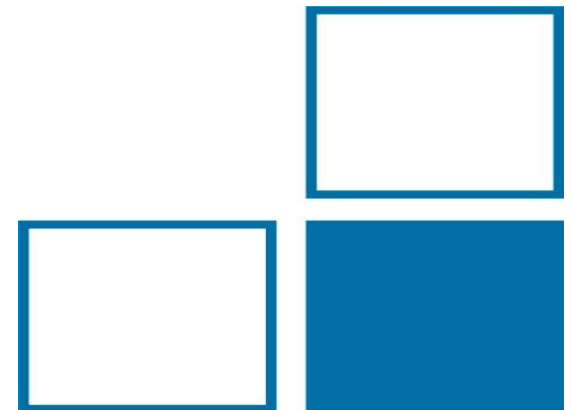
Jörg Martin

joint with Narbota Amanova, Lara Hoffmann, Franko Schmähling, Clemens Elster

Joint European event on Digital Transformation,
20th September 2021



MATHMET



Deep learning in WG „Data analysis and measurement uncertainty“ at PTB

People

Jörg Martin,
Franko Schmähling,
Narbota Amanova,
Lara Hoffmann,
Puneeth Kouloorkar,
Josua Faller (starting in October),
Clemens Elster

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Deep learning
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Overview

Research

Software

Publications

Overview
Deep learning belongs to the class of machine learning methods and typically employs neural networks with many layers to solve tasks such as classification or function approximation. Due to their flexibility neural networks are widely applicable and have shown extraordinary

CONTACT

8.42 Data Analysis and Measurement Uncertainty
Dr. Clemens Elster
Phone: (030) 3481-7492
Email: clemens.elster@ptb.de

Address
Physikalisch-Technische Bundesanstalt
Abbestraße 2–12
10587 Berlin

Experts

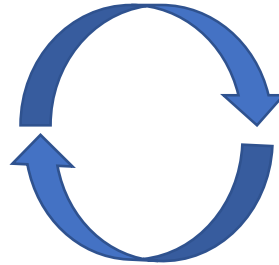
Physikalisch-Technische Bundesanstalt ■ Braunschweig und Berlin

Nationales Metrologieinstitut

Deep learning in WG „Data analysis and measurement uncertainty“ at PTB

Applications

- Optical form measurements
- Image quality in mammography
- ECG diagnostics (planned)



Fundamentals

- Uncertainty
- Explainability
- Robustness

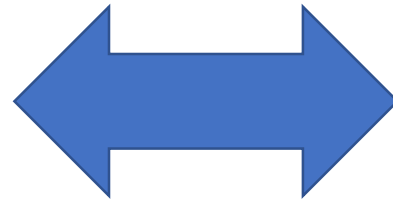
Collaborations

PTB WGs: 4.21, 4.24, 6.24, 8.13
external: TUB, Fraunhofer Heinrich-Hertz

When to apply deep learning?

Physical models

- understood
- predictable
- (often) low dimensional

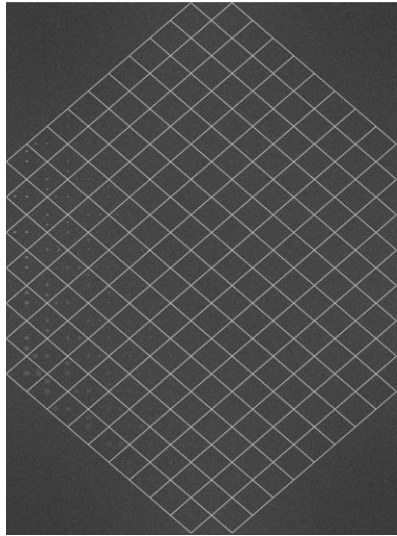


Generic models

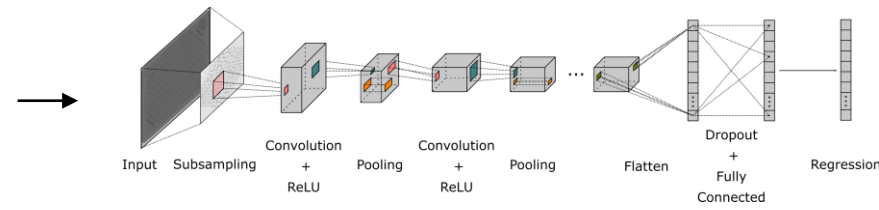
- no model needed
- sometimes more efficient
- updatable

Mammography Image Quality

CDMAM Phantom



neural network



contrast detail curve

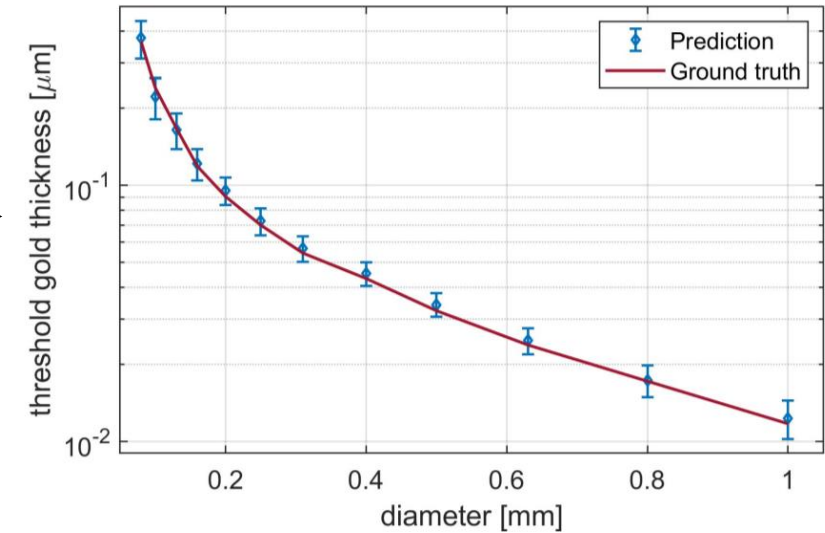
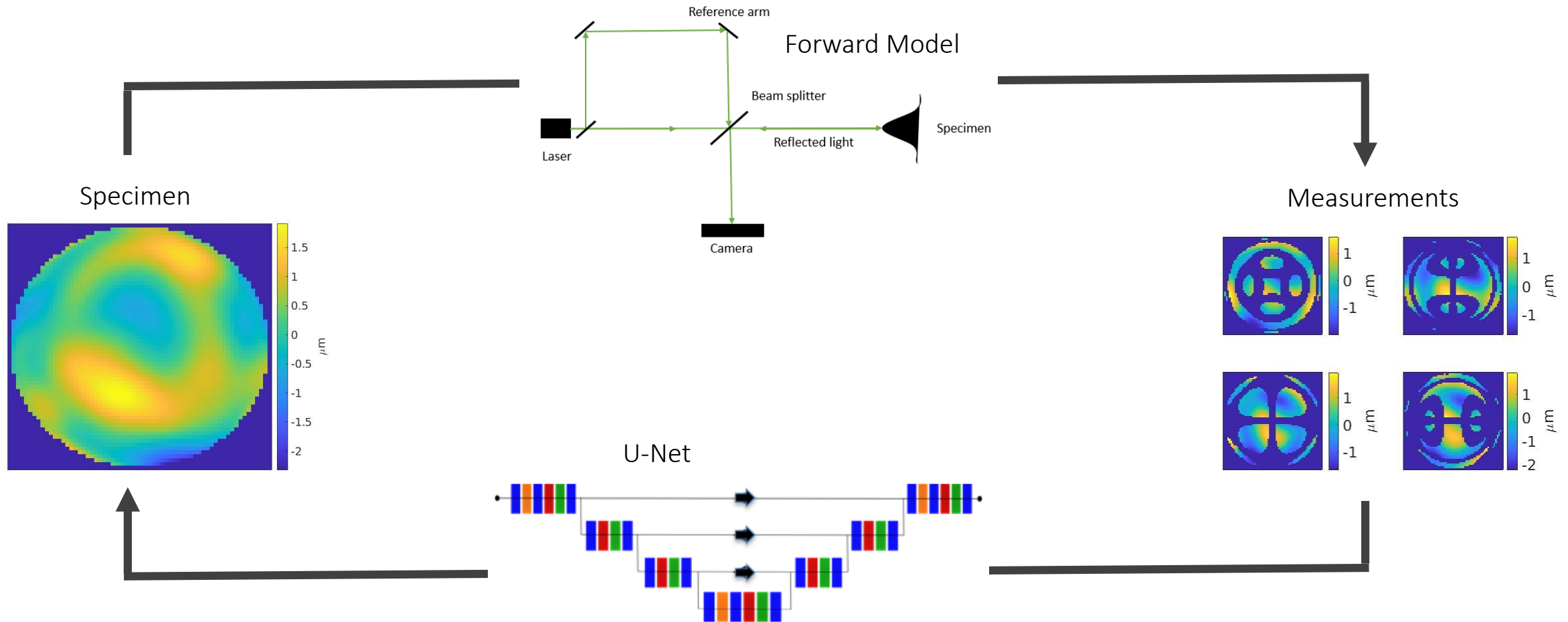


Image quality from images of CDMAM Phantoms via ML

T. Kretz, K-R Müller, T. Schäffter & C. Elster. *Mammography Image Quality Assurance Using Deep Learning*, IEEE Transactions on Biomedical Engineering 2020.

Tilted-Wave Interferometer



L. Hoffmann, C. Elster. *Deep Neural Networks for Computational Optical Form Measurements*. Journal of Sensors and Sensor Systems, 2020.

L. Hoffmann, I. Fortmeier, C. Elster. *Uncertainty Quantification by Ensemble Learning for Computational Optical Form Measurements*. Machine Learning: Science and Technology, 2021.

Robustness

- Out-of-distribution errors
- Adversarial perturbations
- Overfitting

Uncertainty

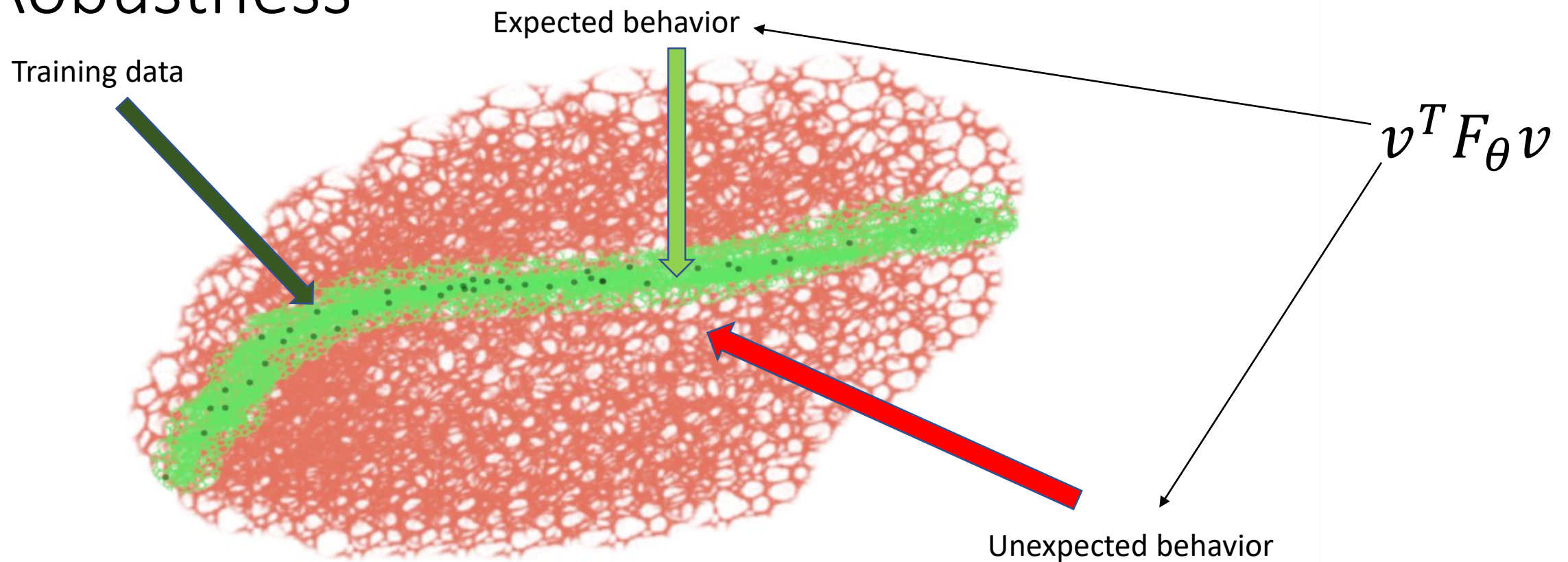
- High dimensional
- „Classical“ methods fail
- Only approximations and no gold standard

Challenges for applying ML

Explainability

- Generic nature
- Black Box
- „Classical“ methods fail

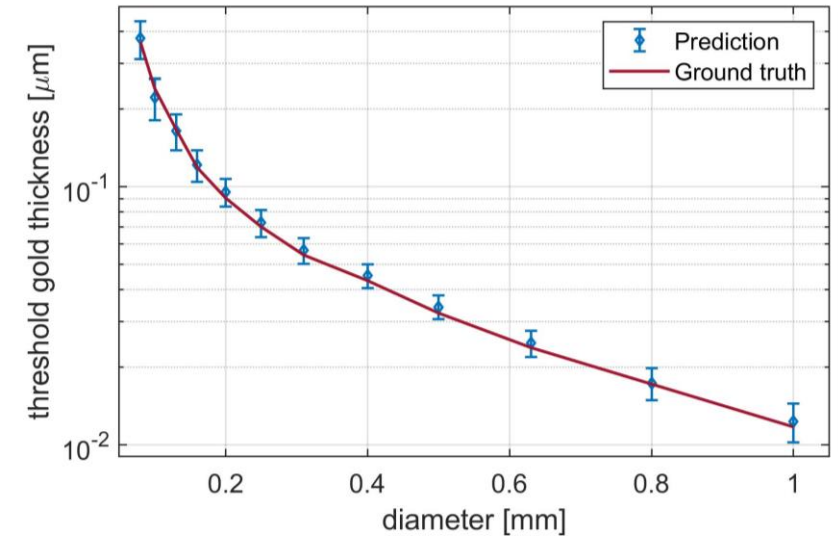
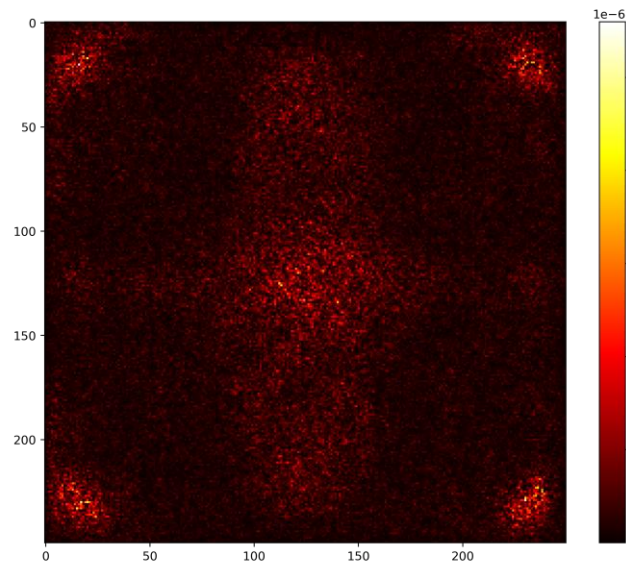
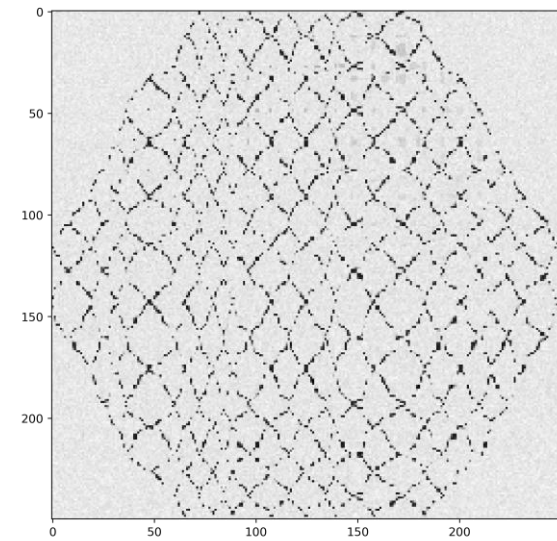
Robustness



J. Martin, C. Elster. *Inspecting adversarial examples using the Fisher information*. Neurocomputing, 2020.

J. Martin, C. Elster. *Detecting unusual input to neural networks*, Applied Intelligence, 2021.

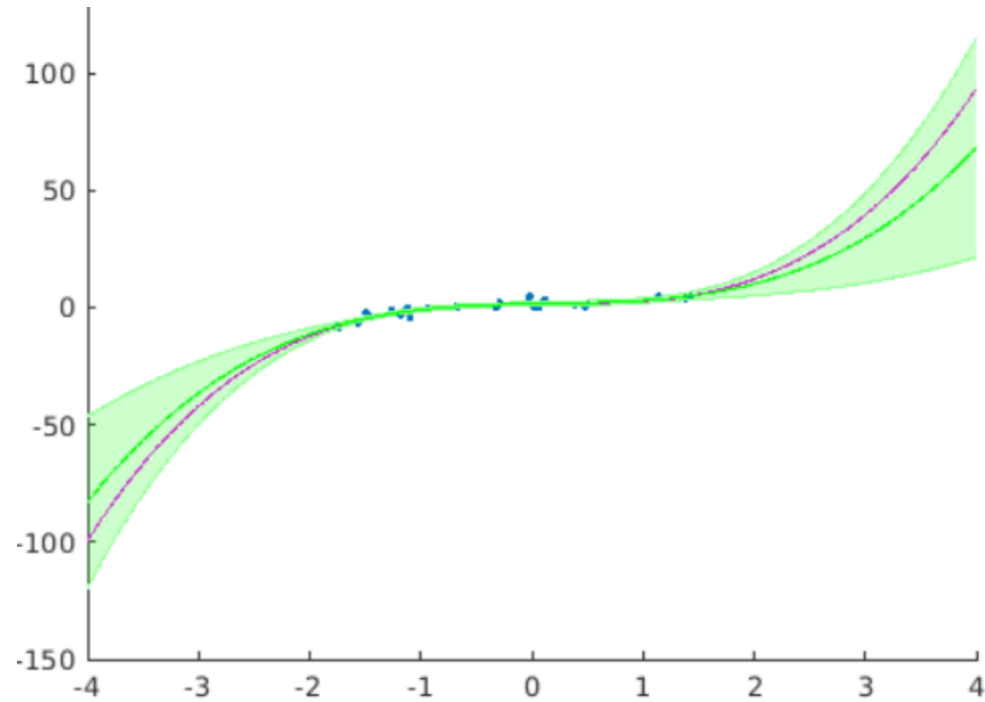
Explainability



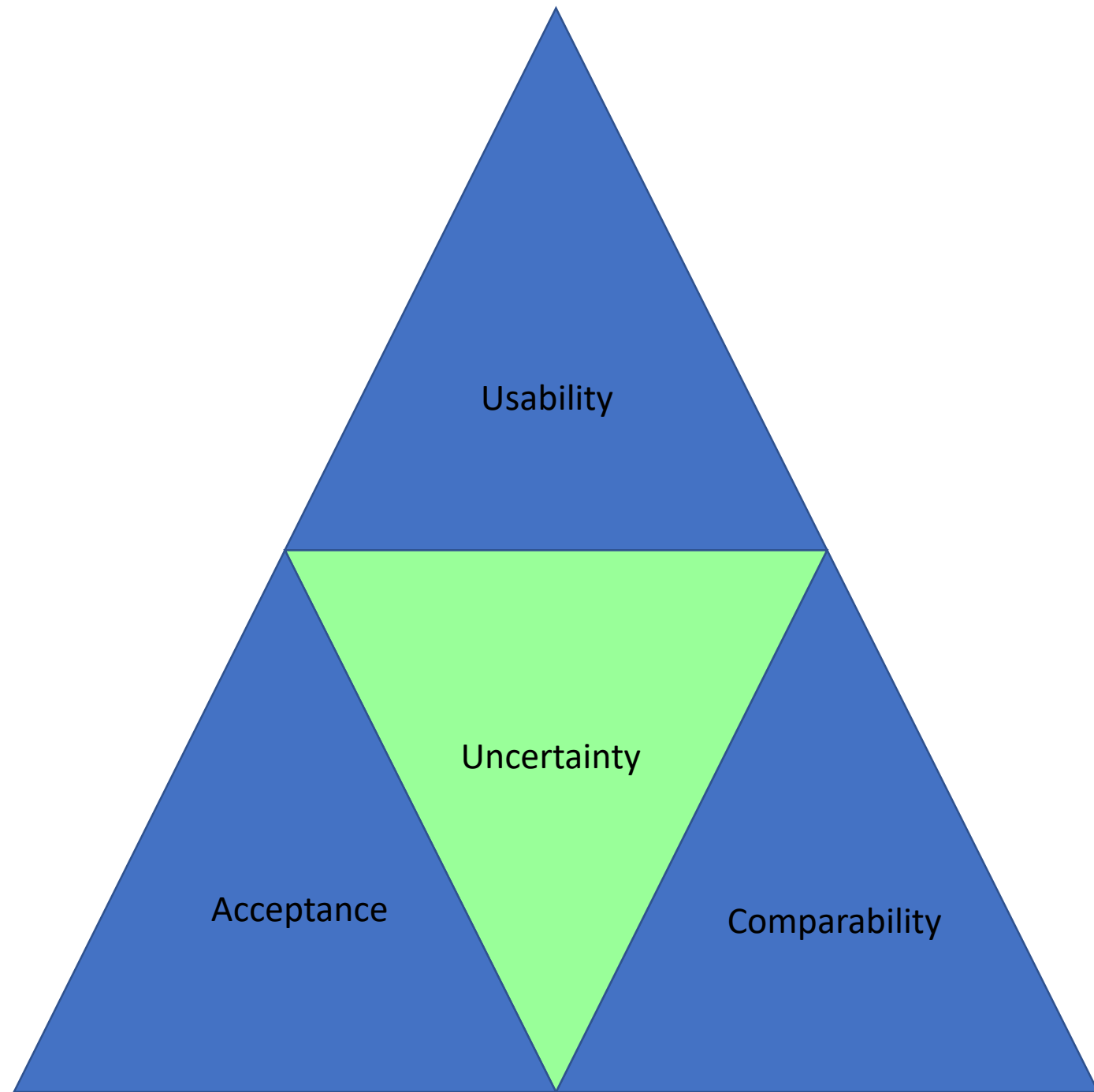
Relevant areas for prediction

work in progress by N. Amanova, J. Martin, C. Elster

Uncertainty



- Various approaches
- No gold standard



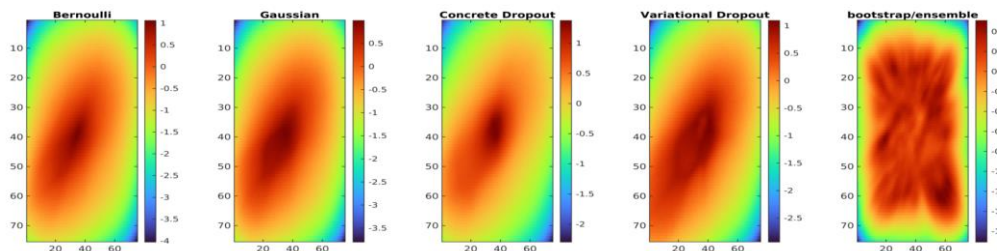
Uncertainty

Research in PTB's
WG „Data analysis
and measurement
uncertainty“

Variational Inference

Errors-in-Variables for deep learning: rethinking aleatoric uncertainty, Martin & Elster (ArXiv)

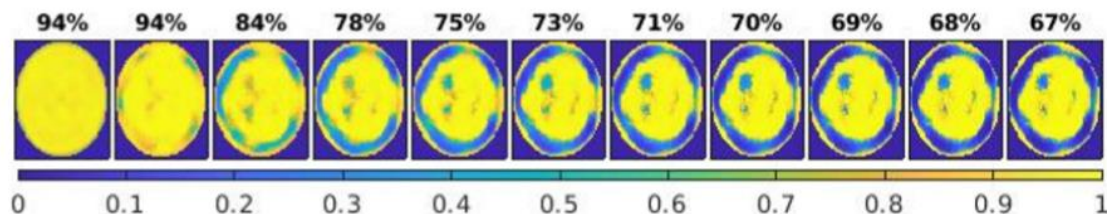
A framework for benchmarking uncertainty in deep regression, Schmähling, Martin & Elster (ArXiv)



$$q_{\phi}(\theta) \approx \pi(\theta|D)$$

Deep Ensembles

Uncertainty Quantification by Ensemble Learning for Computational Optical Form Measurements, Hoffmann, Fortmeier & Elster (Mach. Learn: Sci. T.)



Deep ensembles from a Bayesian perspective, Hoffmann & Elster (ArXiv)

Generative Models

About the regularity of the discriminator in CWGANs, Martin (ArXiv)

$$\mathcal{L}_{\theta} = \mathbb{E}_{y \sim \pi(y)} [\mathcal{W}(\mathcal{G}(y), \pi(x|y))]$$

Conclusions

- Deep learning can be a useful tool in metrology
- Its generic nature raises the need for evaluating and understanding
 - Robustness
 - Explainability
 - Uncertainty
- PTB's WG „Data analysis and measurement uncertainty“:
focus on generic methods (e.g. uncertainty) and specific applications

Publications DL - WG Data analysis and measurement uncertainty

Publications

- L. Hoffmann, I. Fortmeier, C. Elster. *Uncertainty Quantification by Ensemble Learning for Computational Optical Form Measurements*. Mach. Learn.: Sci. Technol., 2021.
- J. Martin, C. Elster. *Detecting unusual input to neural networks*. Applied Intelligence, 2021.
- T. Kretz. *Development of model observers for quantitative assessment of mammography image quality*. PhD Thesis, 2020.
- L. Hoffmann, C. Elster. *Deep Neural Networks for Computational Optical Form Measurements*. JSSS, 2020.
- T. Kretz, K.-R. Müller, T. Schäffter, C. Elster. *Mammography Image Quality Assurance Using Deep Learning*. IEEE Transactions on Biomedical Engineering, 2020.
- J. Martin, C. Elster. *Inspecting adversarial examples using the fisher information*. Neurocomputing, 2020.

Preprints

- J. Martin. *About the regularity of the discriminator in conditional WGANs*. ArXiv, 2021.
- J. Martin, C. Elster. *Errors-in-Variables for deep learning: rethinking aleatoric uncertainty*. ArXiv, 2021.
- L. Hoffmann, C. Elster. *Deep ensembles from a Bayesian perspective*, ArXiv, 2021.
- F. Schmähling, J. Martin, C. Elster, *A framework for benchmarking uncertainty in deep regression*, ArXiv, 2021.