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Uncertainty Quantification for Convolutional Neural Networks

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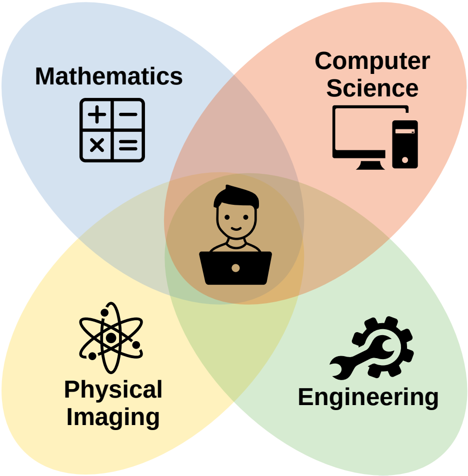
https://applied-math.uibk.ac.at/

PhD-Project

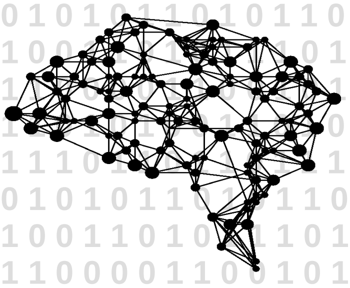


- Started 2019
- Project Partners:
  - LEC GmbH
    `https://www.lec.at/`
  - INNIO Jenbacher GmbH & Co OG
    `https://www.innio.com/`
- Application to large gas engines
- Application to MRI data

Machine Learning

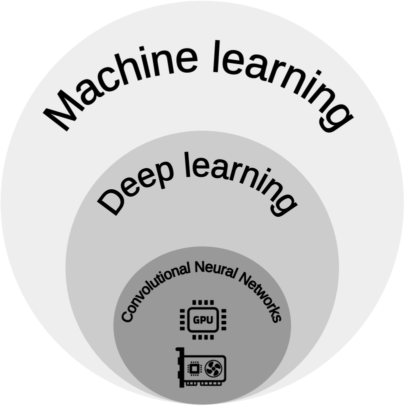
I look at images and apply machine learning.

What is machine learning?



"Machine Learning: A computer is able to learn from experience without being specifically programmed."

What is deep learning?



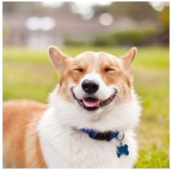
Convolutional Neural Network

Convolutional Neural Networks (CNNs) *learn* properties of an image domain $\mathcal{X}$ or relations between two different image domains $\mathcal{X}$ and $\mathcal{Y}$.

Applications:

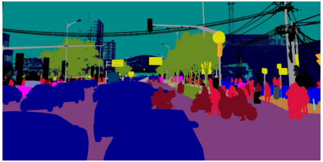
- Classification (feature detection)

cat



dog

- Segmentation (image-to-image)



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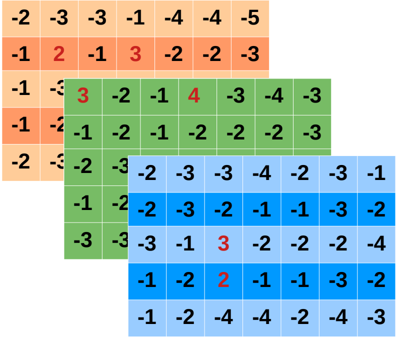
Applications:

- Attribute editing

- Style transfer

Detecting Features

cat eye   cat ear   cat nose



feature maps

Learning Feature Maps

- Training a CNN $\triangleq$ finding appropriate filters $\overbrace{\omega_1, \omega_2, \ldots, \omega_J}^{\Omega}$.
- Image-to-image CNN:

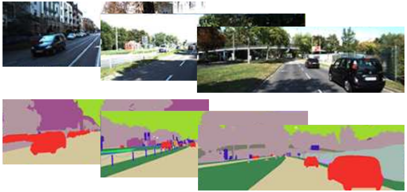
$$f : \mathbb{R}^n \times \mathcal{X} \to \mathcal{Y}, \quad (\Omega, x) \mapsto \text{conv}(\omega_J) \circ \ldots \circ \text{conv}(\omega_1)(x)$$

- In practice: amount of filter parameters $n \approx 1 \times 10^6$ to 1×10^9

Supervised Optimization:

Given N images of interest $x_1, x_2, \ldots, x_N$ (N large)

and corresponding ground truth data $t_1, t_2, \ldots, t_N$ (what we want to predict),



find the **optimal** filters $\Omega_{\text{opt}} = \min_{\Omega \in \mathbb{R}^n} \sum_{i=1}^{N} \text{distance}(f(\Omega, x_i), y_i)$

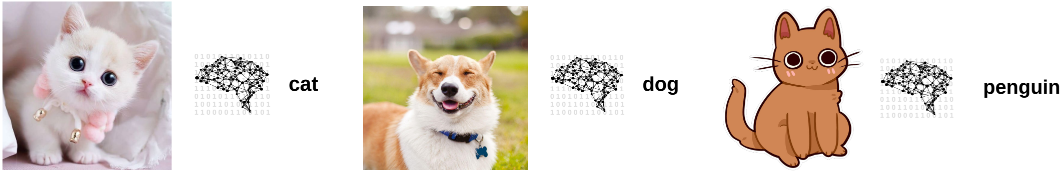
Black Boxes

- CNNs are able to approximate complex image-to-image functions and give good results, at least for images similar to the training data.
- A CNN is referred to as a *black box* model, i.e., while it can approximate any function, studying its structure does not provide any insights of the hidden relation.
- *Just show the model a huge amount of available data until the accuracy reaches the project goals.*

⇒ network behavior on **out-of-distribution data** is unknown

⇒ limits model usability in safety-critical applications

Example (classifier trained on real animals)



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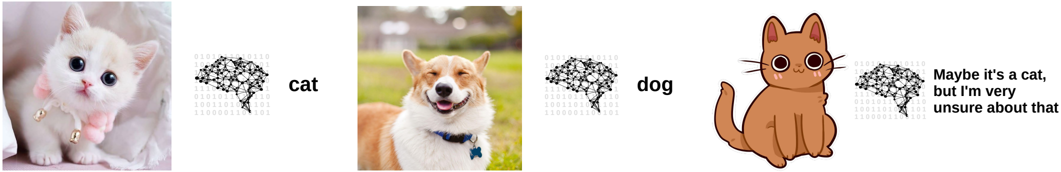
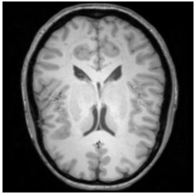
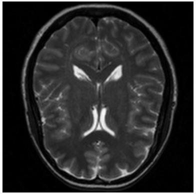
Uncertainty-aware networks



Modality Propagation in MRI

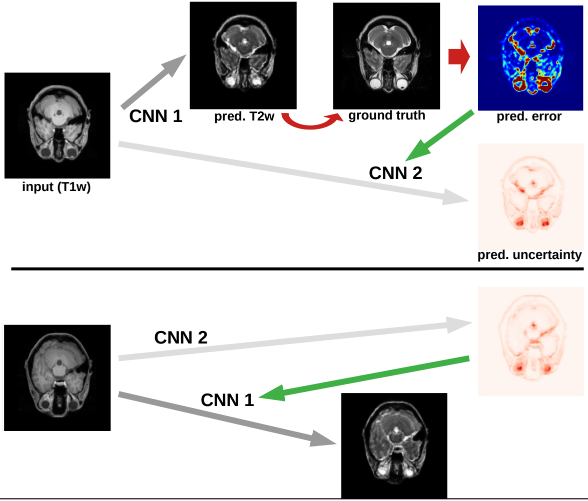
- Application to magnetic resonance imaging (MRI)
- Different available contrasts depending on the pulse sequence:
  - T1-weighted (left): high intensity for tissues (e.g. fat)
  - T2-weighted (right): high intensity for water, liquor





- Acquisition of multiple contrasts is crucial for better diagnosis (e.g. Alzheimer disease)
- However, several successive measurements represent a high burden for the patient with a high cost factor
- **Goal:** Construct an image-to-image function that accounts for uncertainty to synthesize T2-weighted contrasts from T1-weighted measurements

Incorporate Uncertainty

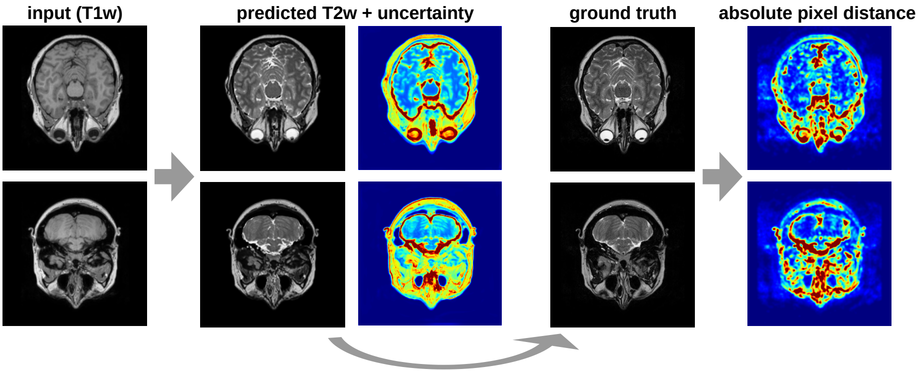


Modality Propagation in MRI

Result:

A position-related confidence map identifies regions in the predictions with less reliability (in the absence of ground truth data)

Qualitative results:



Modality Propagation in MRI

Quantitative results:

- Modeled uncertainty maps can be used to derive an image-based **uncertainty score**
- The uncertainty score highly correlates with the prediction error (pixel-wise absolute distance)
- During in-field application: modeling quality of the T2w contrast can be inferred by the uncertainty score

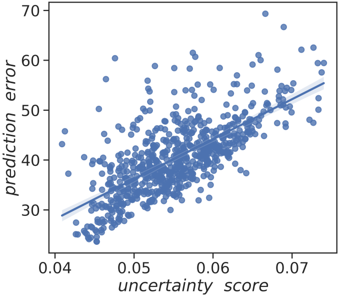


Figure: AC, Haltmeier, Siyal: *Unsupervised joint image transfer and uncertainty quantification using patch invariant networks* (2022)

Concluding Remarks

- Convolutional neural networks enable approximation of complex functions in several imaging tasks
- The uninterpretable structure of CNNs limits their reliability in safety-critical applications
- Leveraging CNNs to uncertainty-aware models yields position-related uncertainty maps during image prediction
- Uncertainty-score enables quality assessment of a prediction during application in the absence of ground truth data

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Thank you for your attention!

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