Institute of Visual Computing – VLO Group

Thomas Pock
Head of the Institute

Me
I studied math and did my PhD at KFU

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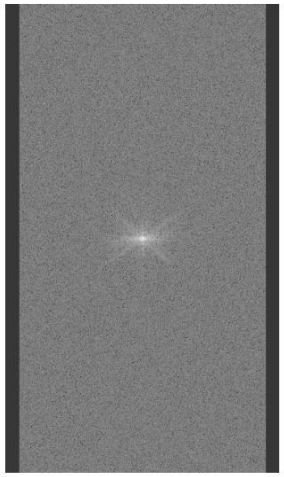
Topics – Inverse Problems

Inverse Imaging problems

- Reconstruct clean image from ugly measurement?
- Applications MRI, CT, denoising, deblurring etc.
- Inversion of the operator $\mathcal{F}$
- Variational solution

Example: MR imaging



Measurement **y**

Known, computable operator $\mathcal{F}$

?

Reconstructed image **x**

$$\min_x ||\mathcal{F}(x) - y||^2 + \mathcal{R}(x)$$

Make sure $\mathcal{F}(x) \approx y$

$\mathcal{R}$ penalizes ugly images → only obtain nice results

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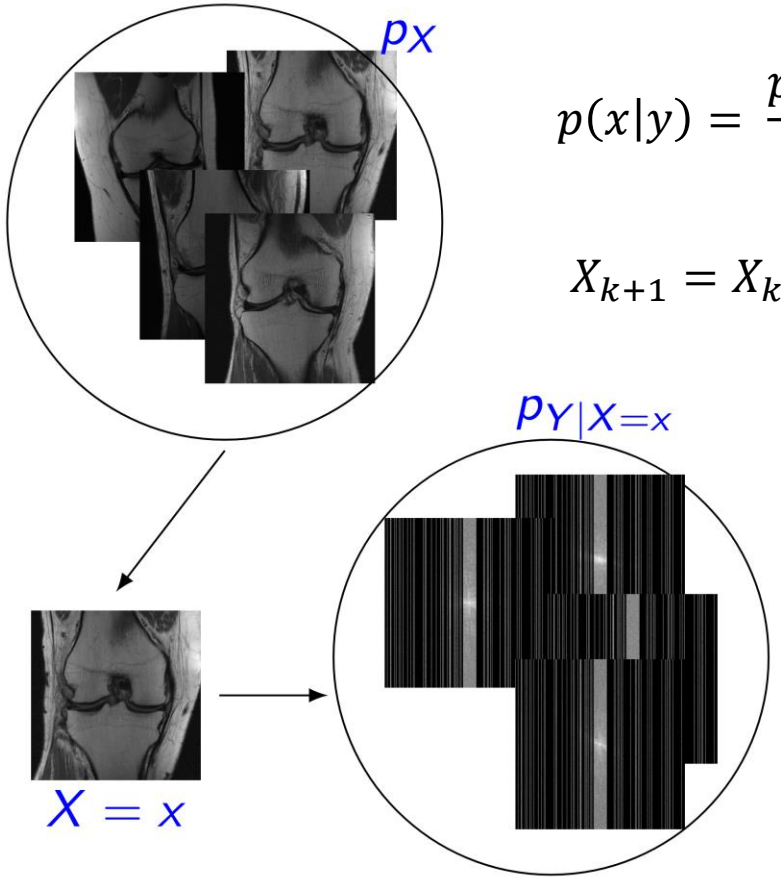
Topics – Bayesian inverse problems

I am currently interested in *Bayesian imaging* approach:

- Images follow a probability distribution
- We can incorporate the measurement y to obtain a *conditional distribution*.
- Problem boils down to generating samples from the distribution.



$$p(x|y) = \frac{p(y|x)p(x)}{p(y)}$$

$$X_{k+1} = X_k + \tau \nabla \log p(X_k|y) + \sqrt{2\tau}\, Z_k$$

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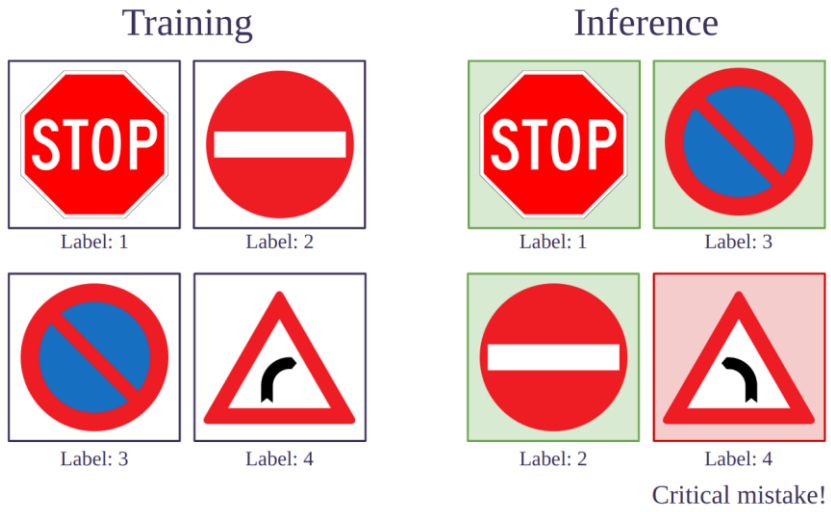
Topics – Out of distribution detection

- What if we feed a model data that is different from what it had been trained on?
- In practice, ML is often overly confident
  - This might lead to critical mistakes!
- Overconfidence can be leveraged to detect out of distribution.
- Applications in medical imaging!

Data at inference might differ from training!



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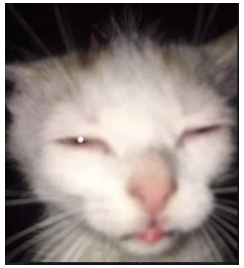
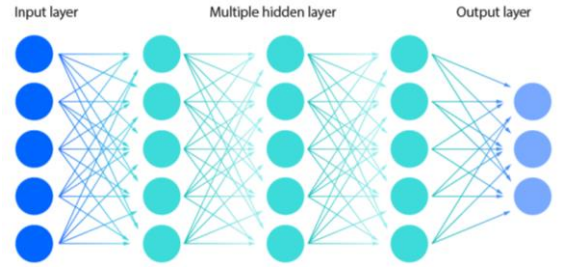
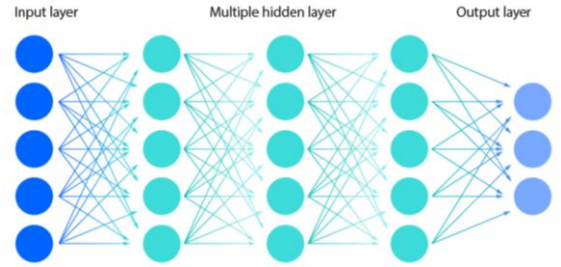
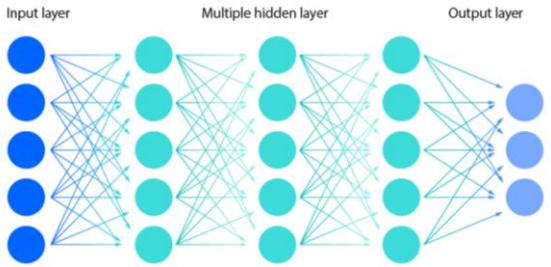




99% cat



99% dog



???

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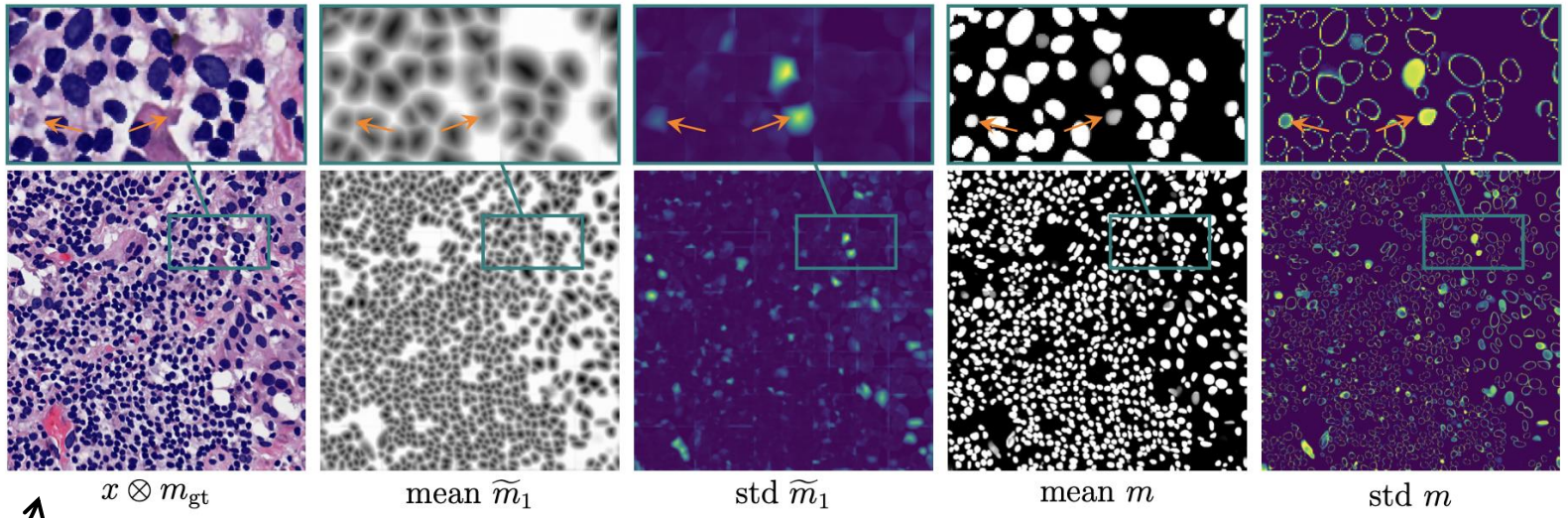
Topics – Image segmentation

Separate different image regions (e.g., different tissues in MRI, CT images)



input image

segmentation result

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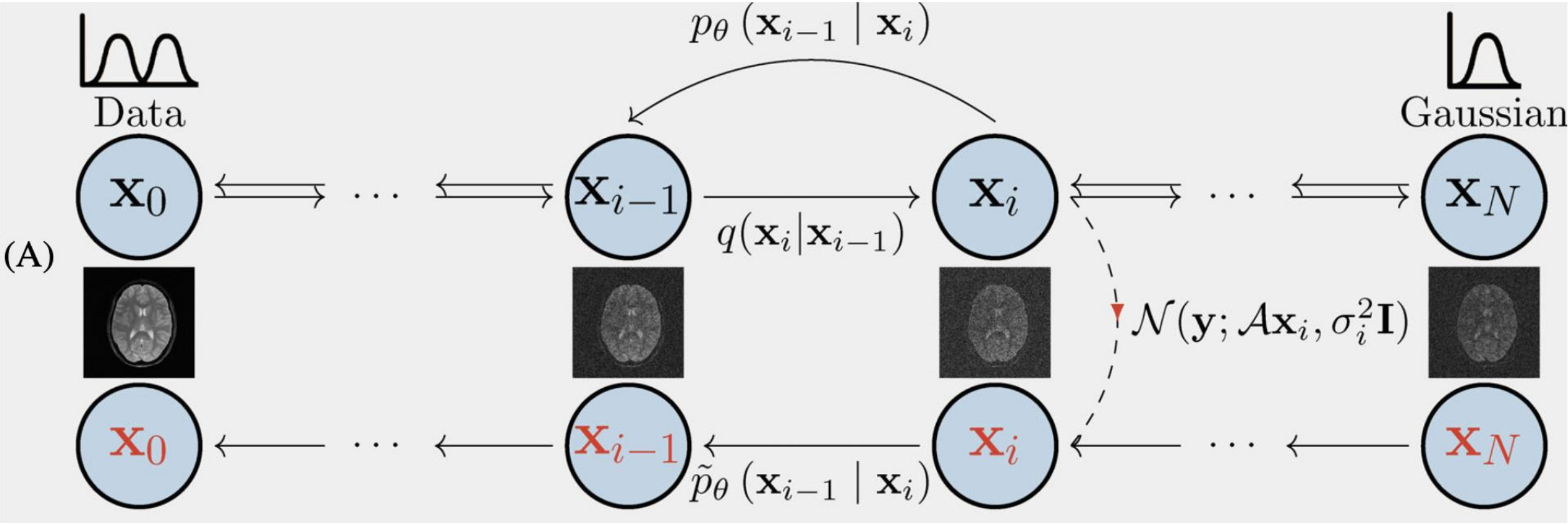
Topics – Diffusion models



Source: Uecker et al. (2023)

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Topics – Bilevel learning

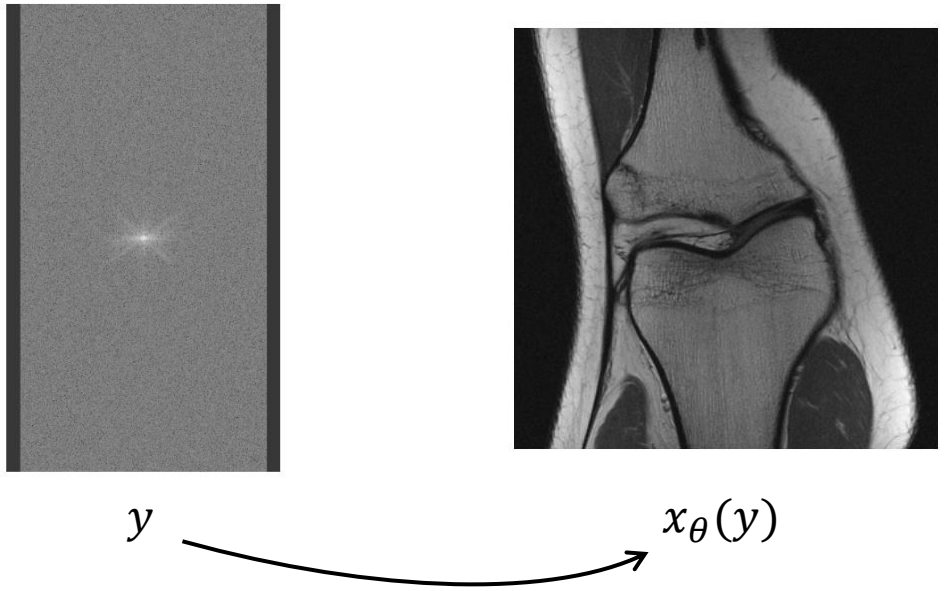
- Solve inverse problem find $x: \mathcal{F}(x) \approx y$ by

$$x_\theta(y) = \underset{x}{\operatorname{argmin}} \, ||\mathcal{F}(x) - y||^2 + \mathcal{R}_\theta(x)$$

where $\mathcal{R}_\theta(x)$ is a neural network with parameters θ

- Bilevel learning: Given training data pairs $(x_i, y_i)_i$

$$\min_\theta \sum_i ||x_\theta(y_i) - x_i||^2$$



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Potential BSc/MSc theses

- Image **sampling**
- **Diffusion models in inverse imaging**
  - Possible applications: MRI, CT
- **Flow matching vs diffusion models** for image sampling
- Math theses
  - Work out **mathematical proofs** of convergence of certain **sampling methods.**
  - Work out math for **stochastic differential equations** (this is an extremely relevant field in ML)

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What a thesis will look like

Part 1: Literature

- Reading papers covering the topic
- Re-implementing published method(s)
- Acquiring deeper understanding

Part 2: Original research

- Adding some alterations to known methods
- Trying to improve upon the literature
- Here you will receive more guidance

- Regular feedback/meetings with supervisor
- Balance of implementation and theory
  - of course we will implement algorithms
  - but we also want to understand and analyze them mathematically.

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