Healing X-ray scattering images with the Deep Image Prior

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Tetra Pak 3

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Background

The problem

- Tetra Pak® studies the structure and material orientation of semi-crystalline polymers used in polymer tops and opening devices.
- To do this, the X-ray measuring techniques *SAXS* and *WAXS* are used.
- Physical limitations in the measuring equipment give rise to scattering-free sections in the result images.
- Our goal is to inpaint those empty regions.
- Previous work uses a rule based, statistical method [1]
- We wanted to use machine learning

Input image example

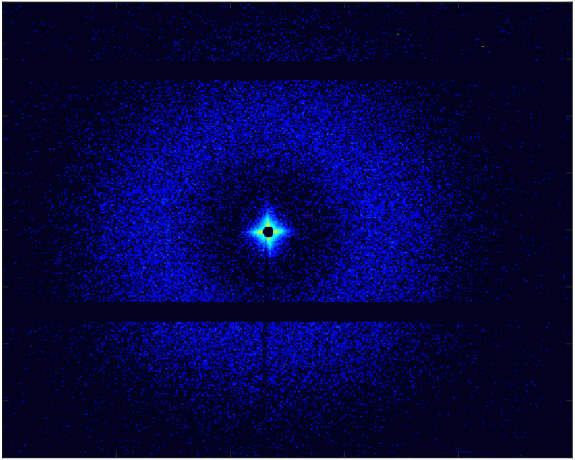


Figure 1: An example input image. There are two horizonatal lines, a dot in the middle from the beamstop and a less visible vertical line that originates from the beamstop holder.

THEORY

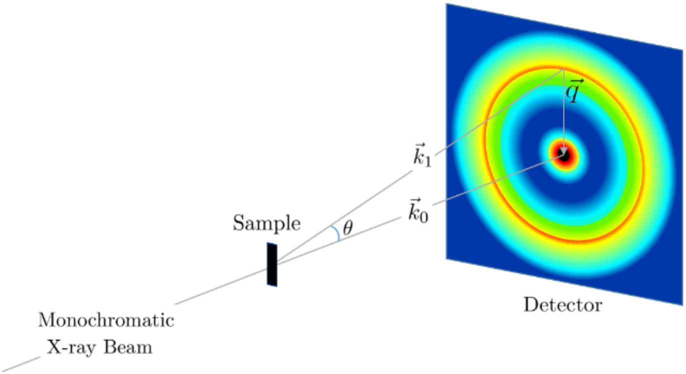
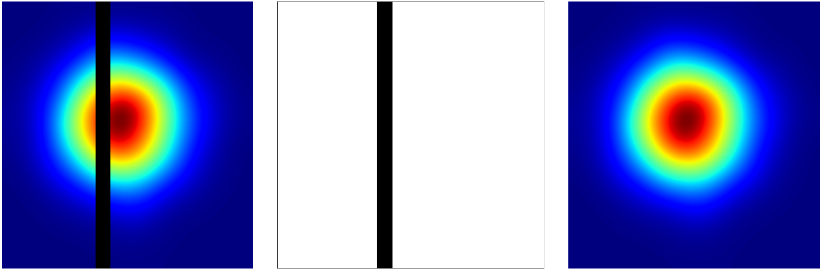


Figure 2: The experimental setup of SAXS/WAXS [2].

The task of reconstructing the **image** x from the **occluded image** x_0 with *missing pixels* corresponding to some **binary mask** $m \in \{0, 1\}^{\text{width}\times\text{height}}$.



(a) x_0 (b) m (c) x

Figure 3: Illustration of the three different concerned image types; the occluded image x_0 with missing pixels, the mask m and the constructed image x.

The Deep Image Prior

- Convolutional neural network model for image restoration proposed in 2017 [3]
- Trains on only one image, the one to be restored
- Achieves close to state-of-the-art results in super-resolution, inpainting etc

The Deep Image Prior: optimization task

Inpainting (optimization) task:

$$x^* = \underset{x}{\operatorname{argmin}} \; \|(x - x_0) \odot m\|^2 + R(x), \tag{1}$$

inpainted image x^*, regularizer $R(x)$, element-wise matrix multiplication $\odot$. The deep image prior replaces this by

$$\theta^* = \underset{\theta}{\operatorname{argmin}} \; \|(f_\theta(z) - x_0) \odot m\|^2 , \tag{2}$$

initial image z, neural network f_θ, network parameters θ.

The Deep Image Prior: training algorithm

1. **Initialize** network weights and initial image z, e.g. noise or meshgrid.
2. Optional: Add normal **noise** to initial image and/or weights.
3. **Forward propagate** through the network. The output is an image.
4. **Mask** the output.
5. Calculate MSE **loss** using the masked output and the target, $x_0 \odot m$.
6. **Backpropagate** and **update** the weights with Adam.
7. **Repeat** N times from step 2.

Network architecture

The Deep Image Prior inpainting network is an autoencoder with skip connections. It consists of four main layer types:

- 2D convolutional layers
- pooling
- LeakyReLU activation
- normalization

Preparations

Masking

- Automatic cropping
- Convertion to grayscale
- Normalization
- Manual user input for
  - beamstop position
  - beamstop holder position
  - horizontal and vertical lines threshold
- Combine masks

Masking

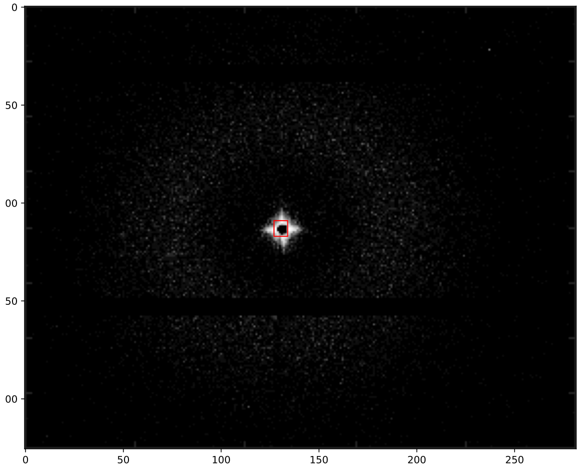


Figure 4: Selected region to look for beamstop in example scatter plot.

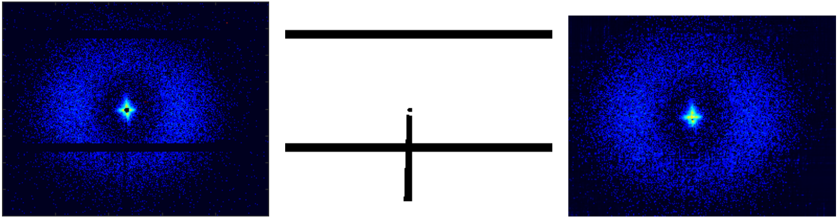
Hyperparameter tuning

- Goal: find the best combination of hyperparameters
- `lr`: learning rate of the optimization algorithm
- `param_noises`: whether to add normal noise to weights
- `reg_noise_stds`: standard deviation of noise added to iteration images

Hyperparameter	Values tested
`lr`	{0.0001, 0.001, 0.01, 0.05, 0.1}
`param_noises`	{False, True}
`reg_noise_stds`	{0.3, 0.03, 0.003, 0}

RESULTS

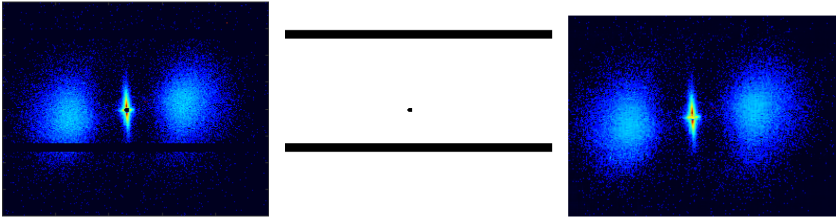
Best inpainting results



(a) Before (b) Mask (c) After

Figure 5: Original image (left), mask (middle) and best in-painted image from the hyperparameter grid search (right).

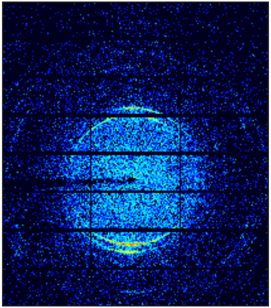
Best inpainting results



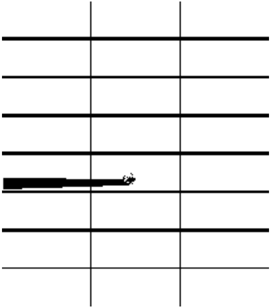
(a) Before (b) Mask (c) After

Figure 6: Original image (left), mask (middle) and best in-painted image from the hyperparameter grid search (right).

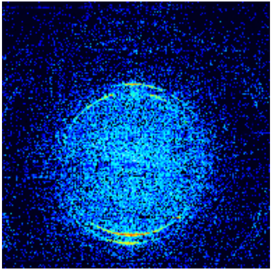
Best inpainting results



(a) Before



(b) Mask



(c) After

Figure 7: Original images (left), mask (middle) and best in-painted images from the hyperparameter grid search (right).

Bad inpaintings

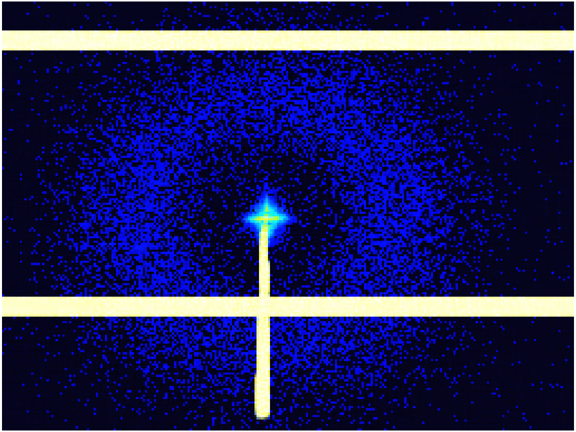
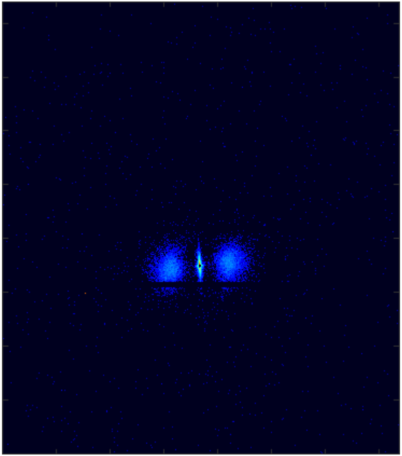
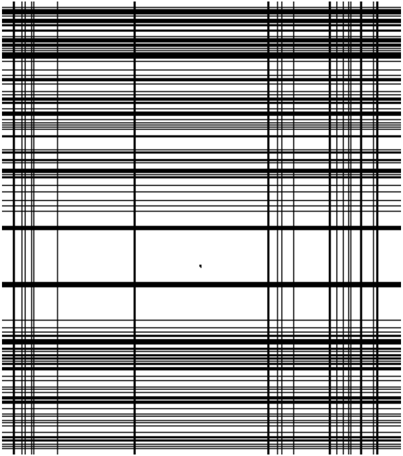


Figure 8: Example of bad inpainting from hyper parameter search.

Bad masks



(a) Image



(b) Mask

Figure 9: Image (left) and bad masking result (right).

Conclusions

Conclusions

- The deep image prior can successfully inpaint occluded X-ray scattering images
- Hyperparameter tuning necessary for optimal setting
- Fully automatic masking is a topic for future research
- Utilize symmetry planes in specific images for future work

References

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