Single Instance or Data Driven: Two ways of solving inverse problems

Wenjie Zhang[1], Yuxiang Wan[1], Zhong Zhuang[2], Taihui Li[1], Hengkang Wang[1], Ju Sun[1]

[1] Department of Computer Science and Engineering, University of Minnesota

[2] Department of Physics and Astronomy, University of California, Los Angeles

1. Background

Inverse Problems:

Estimating **Ground Truth** $\boldsymbol{x}$ from **Observation** $\boldsymbol{y} \approx \boldsymbol{f}(\boldsymbol{x})$

Methods:

- Maximum A posteriori Method

$$\min_{\boldsymbol{x}} \ell\big(\boldsymbol{y}, \boldsymbol{f}(\boldsymbol{x})\big) + \boldsymbol{\lambda}\boldsymbol{\Omega}(\boldsymbol{x})$$

- **Single Instance Method**
- **Data Driven Method**

2. Single Instance Methods

2.1 Deep Image Prior

$$\boldsymbol{x} \approx \boldsymbol{G}_{\boldsymbol{\theta}}(\boldsymbol{z})$$

$$\min_{\boldsymbol{\theta}} \underbrace{\ell\big(\boldsymbol{y}, \boldsymbol{f} \circ \boldsymbol{G}_{\boldsymbol{\theta}}(\boldsymbol{z})\big)}_{\text{Data Fitting}} + \underbrace{\boldsymbol{\lambda}\boldsymbol{\Omega} \circ \boldsymbol{G}_{\boldsymbol{\theta}}(\boldsymbol{z})}_{\text{Regularizer}}$$

2.2 Blind Image Deblur

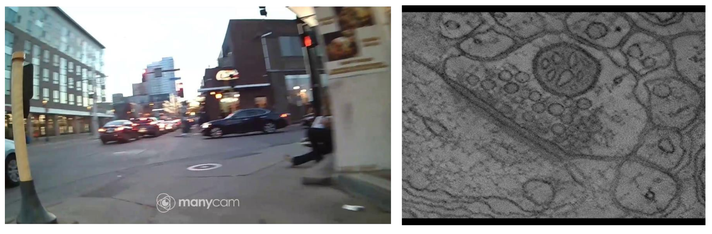
Blur Input $\boldsymbol{y}$ Sharp GT $\boldsymbol{x}$ Blur Kernel $\boldsymbol{k}$

Forward Model of Blurring Process

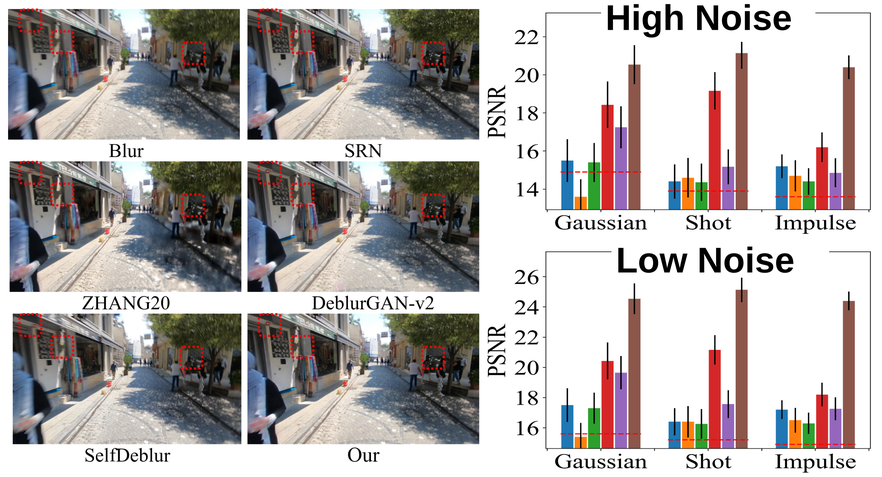
$$\boldsymbol{y} = \boldsymbol{k} * \boldsymbol{x} + \boldsymbol{n}$$

Challenges for the Real-World Deblur

- **Unknown Kernel Size**
- **substantial noise**



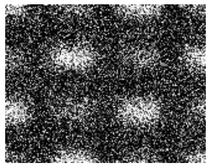
Our Method: DIP + SIREN



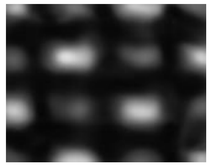
Scientific Application

Scanning transmission electron microscopy (STEM)

Challenges: low signal-to-noise ratios, Unknown kernel Size, no reliable ground truth

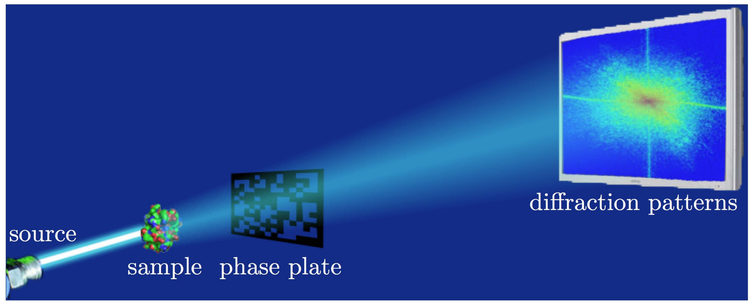


Blur and Noisy Input



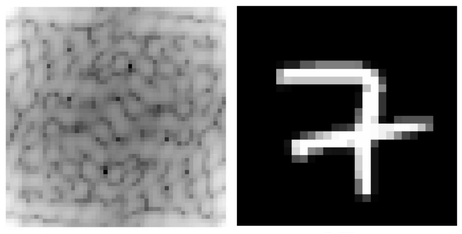
BID Reconstruction

2.3 Phase Retrieval



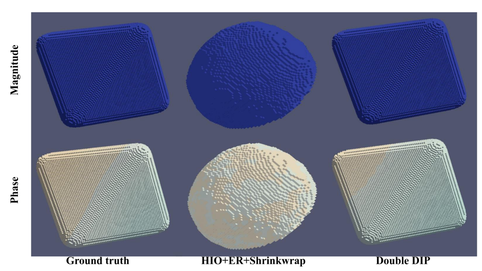
Forward Model:

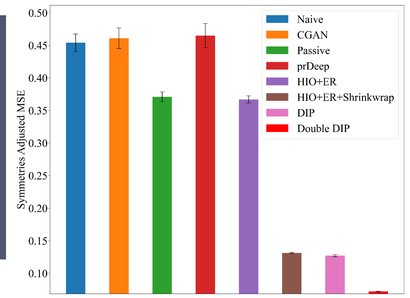
$$\boldsymbol{y} = |\mathcal{F}(\boldsymbol{x})|^2$$



Observation $\boldsymbol{y}$ GT $\boldsymbol{x}$

Our method: Double-DIP

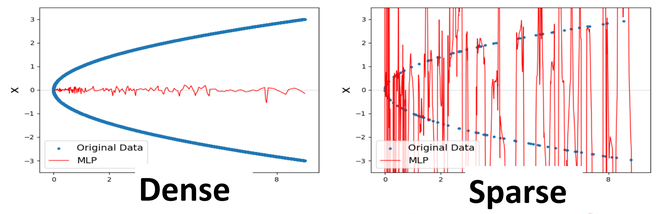




3. Data Driven Methods

3.1 Curse of Data Driven Methods - Symmetries

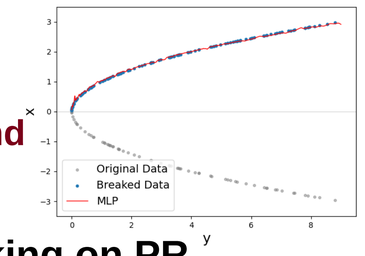
Square Root Example $y = x^2$



Larger Dataset, Worse Performance ☹

3.2 Symmetry Breaking

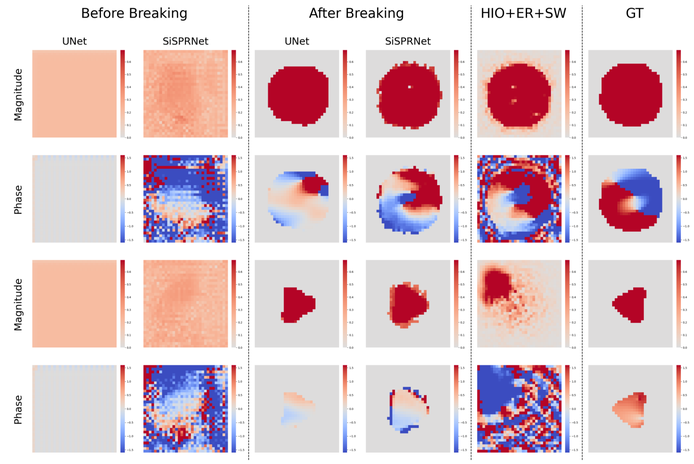
Mapping the data points to a **Smallest, Representative and Connect Set**



3.3 Apply Symmetry Breaking on PR

Our Solution – two stage symmetry breaking

Results



Ref: [1] Zhuang, Z., Li, T., Wang, H., & Sun, J. (2024). Blind image deblurring with unknown kernel size and substantial noise. International Journal of Computer Vision. [2] Zhuang, Z., Yang, D., Hofmann, F., Barmherzig, D., & Sun, J. (2023). Phase Retrieval Using Double Deep Image Priors. NeurIPS 2023 Workshop on Deep Learning and Inverse Problems. [3] Zhang, W., Wan, Y., Zhuang, Z., & Sun, J.(2024). What is Wrong with End-to-End Learning for Phase Retrieval? arXiv preprint arXiv:2403.15448. [4] K. Jaganathan, Y. C. Eldar & B. Hassibi Phase Retrieval: An Overview of Recent Developments