Data Driven Computational Imaging Survey

Tristan Swedish
CVPR Tutorial

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Data-Driven Computational Imaging

Time	Title	Presenter
08:30 - 08:50	Introduction to Computational Imaging	Guy Satat (MIT)
08:50 - 09:15	Data-Driven Computational Imaging Survey	Tristan Swedish (MIT)
09:15 - 10:00	Data-Driven Non-line-of-sight Imaging and 3D Reconstruction	Guy Satat (MIT)
10:00 - 10:20	Break	
10:20 - 11:00	Rendering and Simulation for Data-Driven Computational Imaging	Tristan Swedish (MIT)
11:00 - 12:00	Visual Sensing Using Machine Learning	Vivek Boominathan (Rice), Ashok Veeraraghavan (Rice)

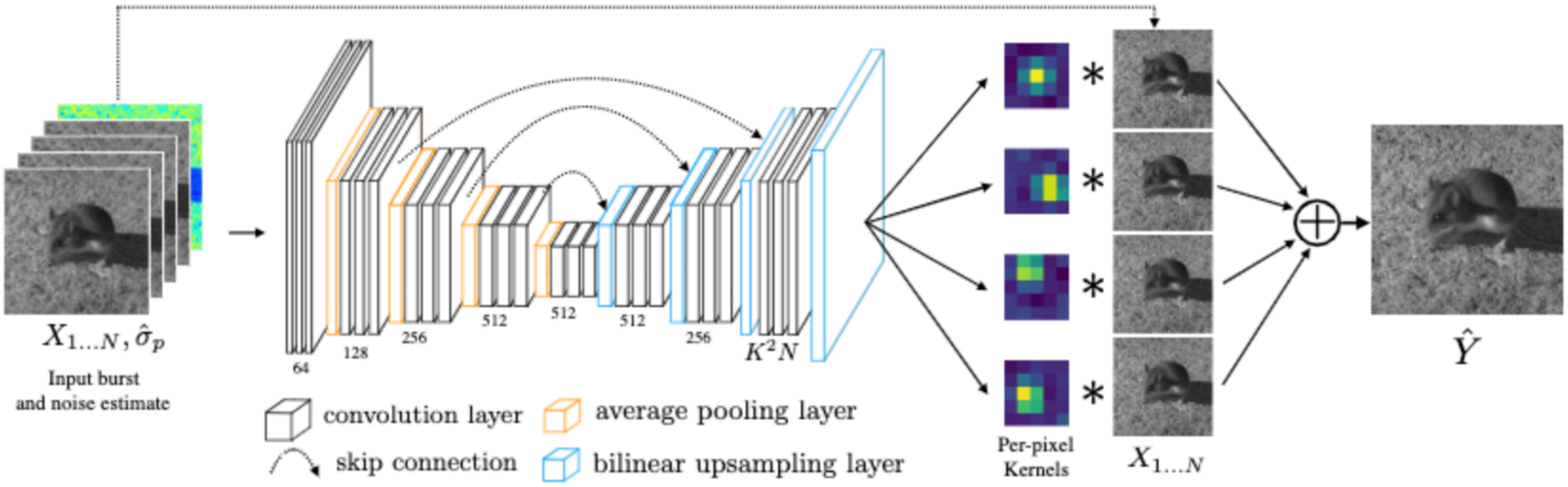
Overview

Computational Imaging is Diverse:

- Low-level Processing (Denoising and Demosaicking)
- 3D Imaging
- Lensless, Speckle, Scattering
- Non-line-of-sight
- Imaging System Design
- Tomography and Deconvolution
- Microscopy

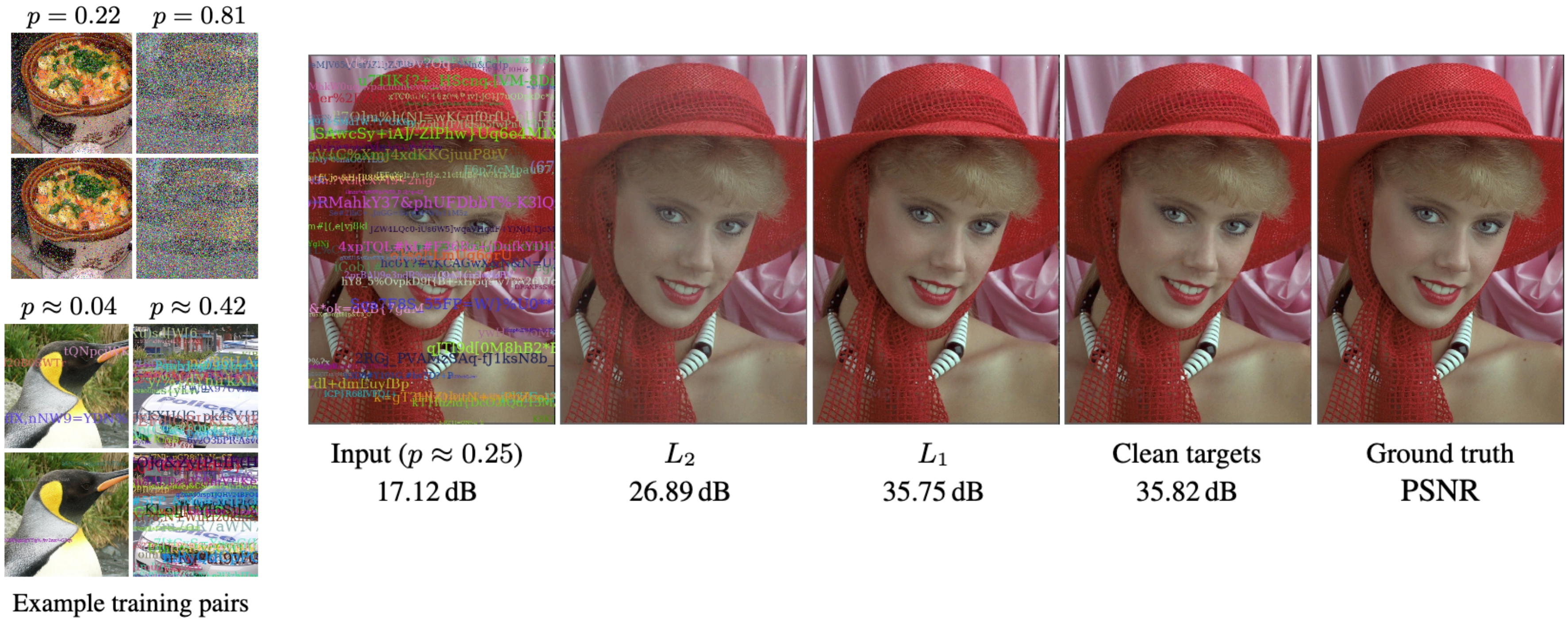
Low Level Processing (de-noising, de-mosaicking)

Burst Denoising with Kernel Prediction Networks



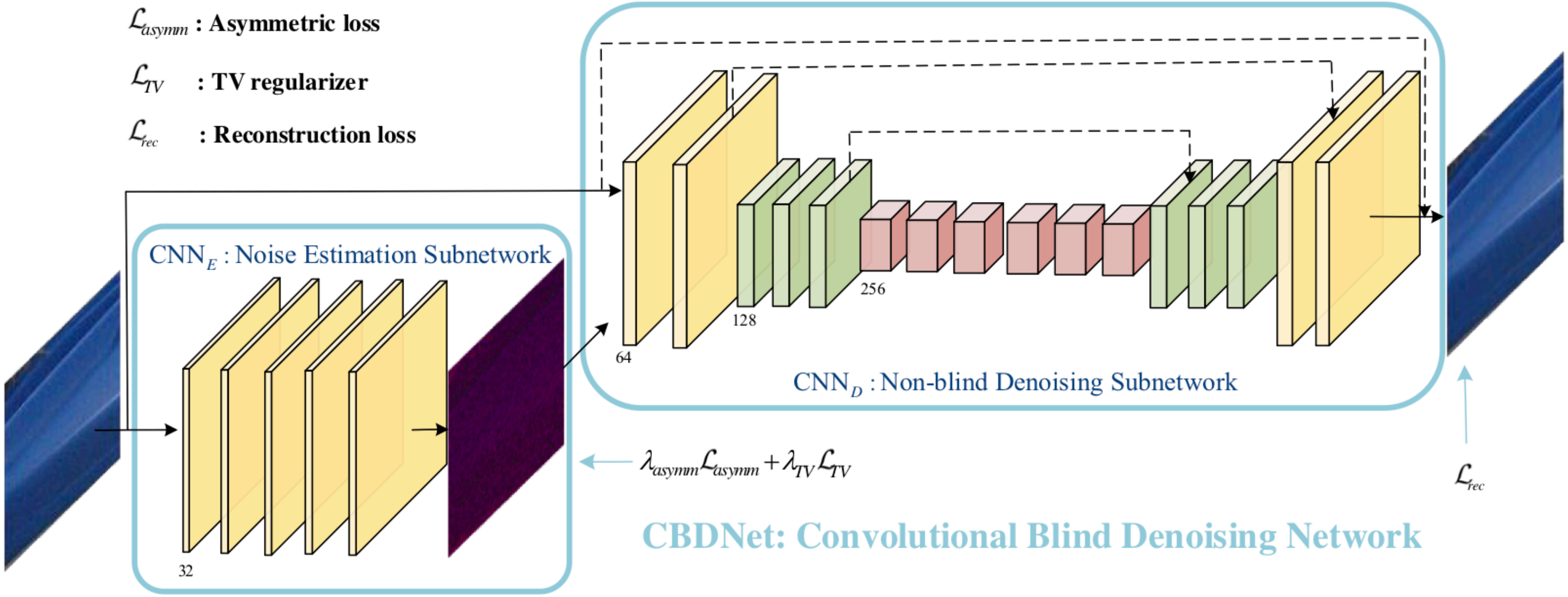
B. Mildenhall, J. T. Barron, J. Chen, D. Sharlet, R. Ng, R. Carroll. *Burst Denoising with Kernel Prediction Networks*. CVPR, 2018.

Noise2Noise



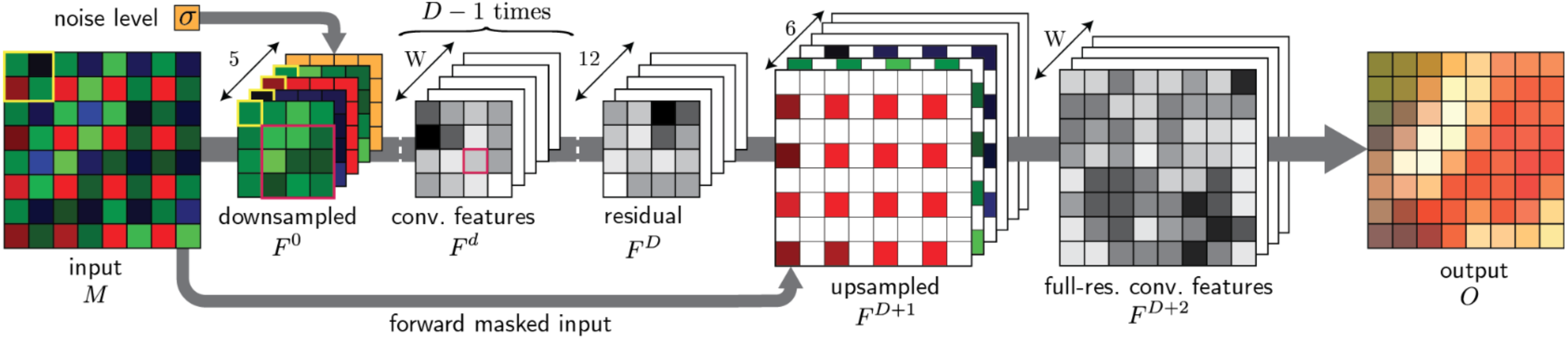
Jaakko Lehtinen, Jacob Munkberg, Jon Hasselgren, Samuli Laine, Tero Karras, Miika Aittala, Timo Aila. *Noise2Noise: Learning Image Restoration without Clean Data*. ICML, 2018.

Toward Convolutional Blind Denoising of Real Photographs



S. Guo, Z. Yan, K. Zhang, W. Zuo and L. Zhang. *Towards Convolutional Blind Denoising of Real Photographs*. CVPR, 2019.

Deep Joint Demosiacking and Denoising



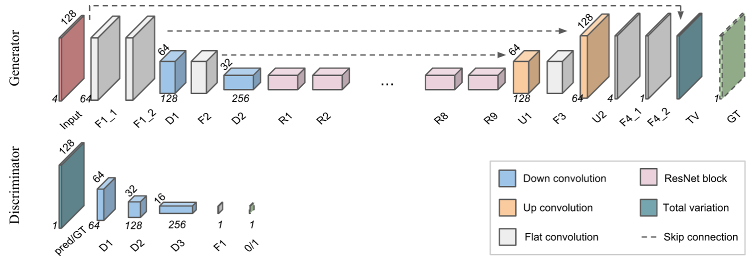
Michaël Gharbi, Gaurav Chaurasia, Sylvain Paris, Frédo Durand. *Deep joint demosaicking and denoising*. Trans. on Graphics (TOG), 2016.

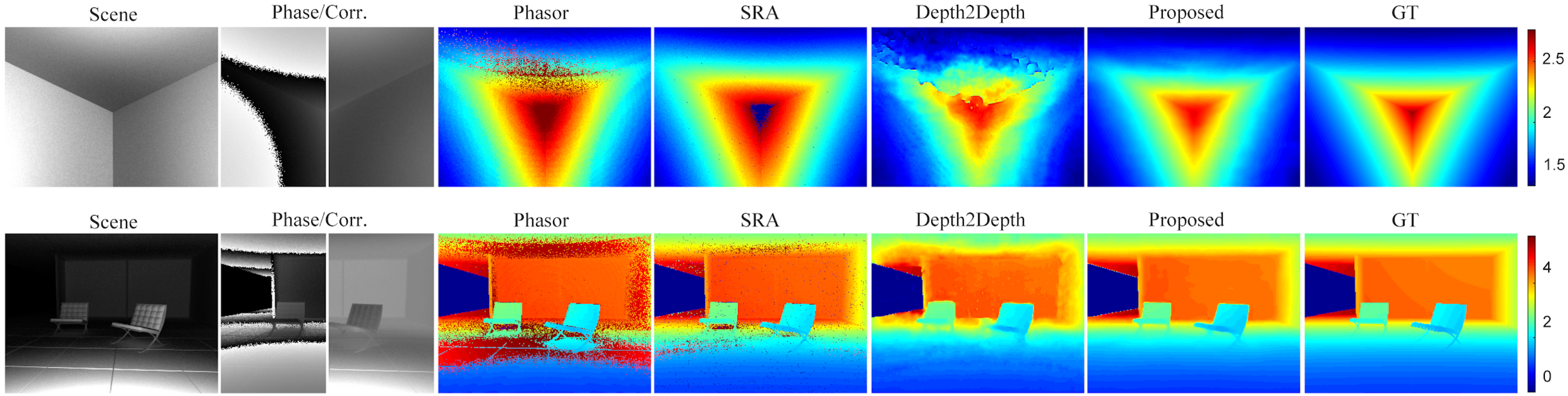
Deep Joint Demosiacking and Denoising

Michaël Gharbi, Gaurav Chaurasia, Sylvain Paris, Frédo Durand. *Deep joint demosaicking and denoising*. ACM Trans. on Graphics (TOG), 2016.

3D Imaging

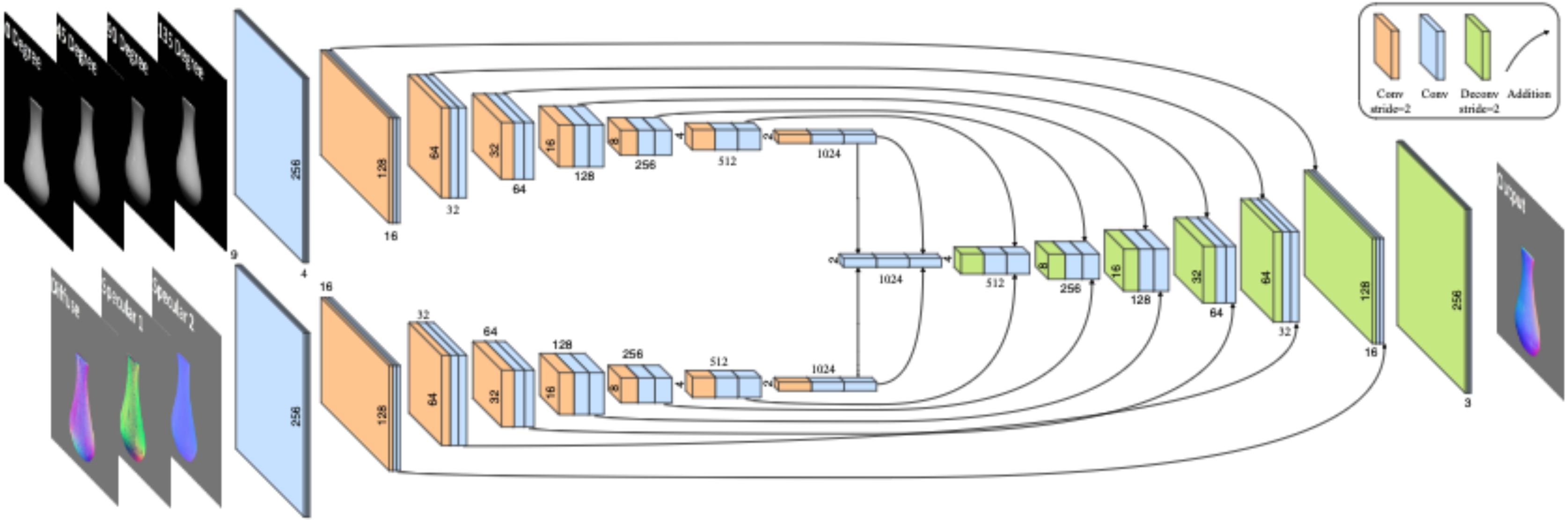
Deep End-to-End ToF Imaging





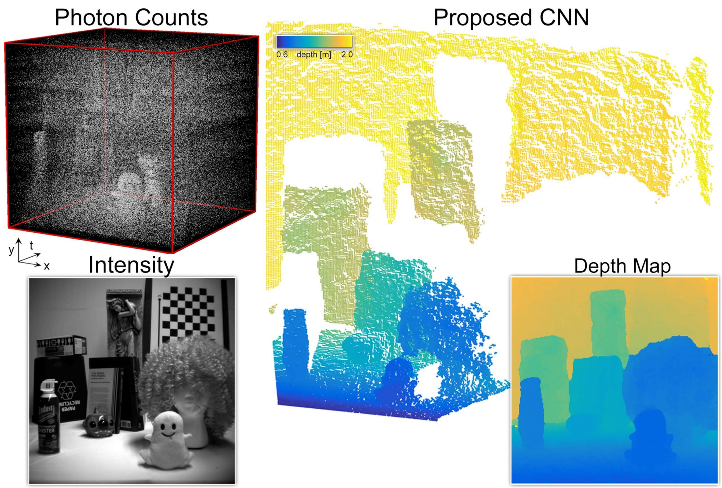
Shuochen Su, Felix Heide, Gordon Wetzstein, Wolfgang Heidrich. *Deep End-to-End ToF Imaging*. CVPR, 2018.

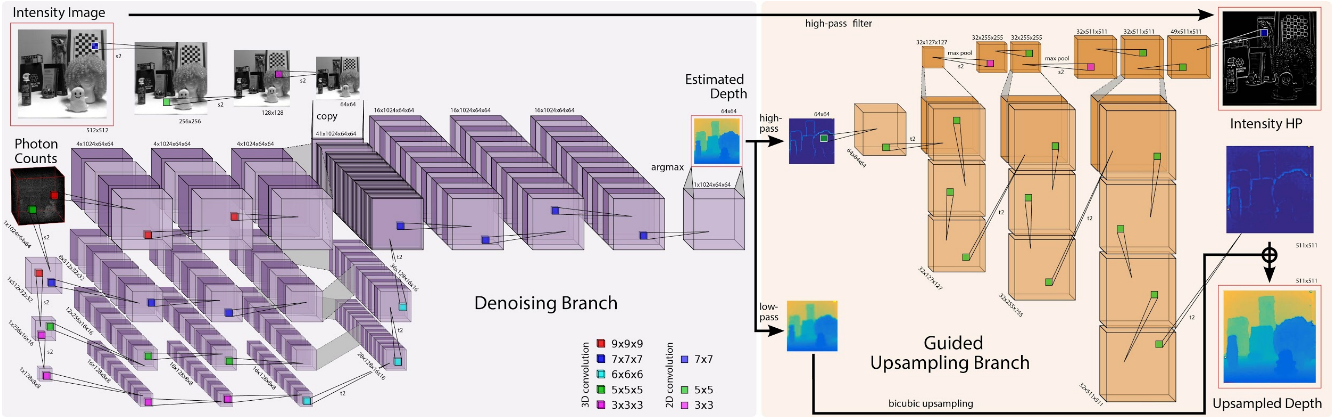
Physics Based Neural Network for Shape from Polarization



Yunhao Ba, Rui Chen, Yiqin Wang, Lei Yan, Boxin Shi, Achuta Kadambi. *Physics-based Neural Networks for Shape from Polarization*. Arxiv, 2019.

Single Photon 3D Imaging

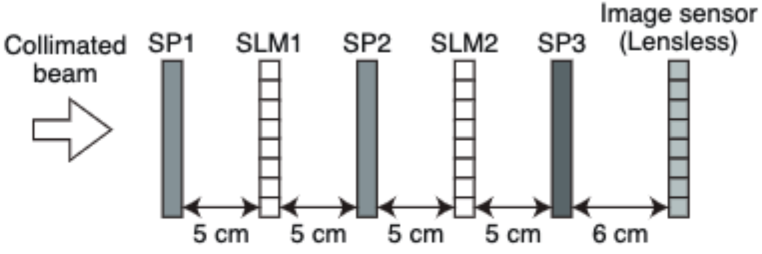




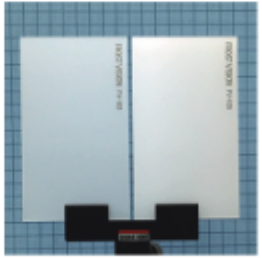
David B. Lindell, Matthew O'Toole, and Gordon Wetzstein. *Single-Photon 3D Imaging with Deep Sensor Fusion*. ACM Trans. Graph., 2018.

Lensless, Speckle, Scattering

Learning Based Imaging through Scattering Media



(a)



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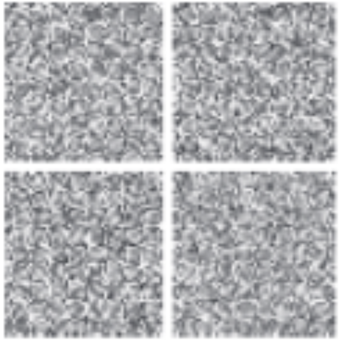


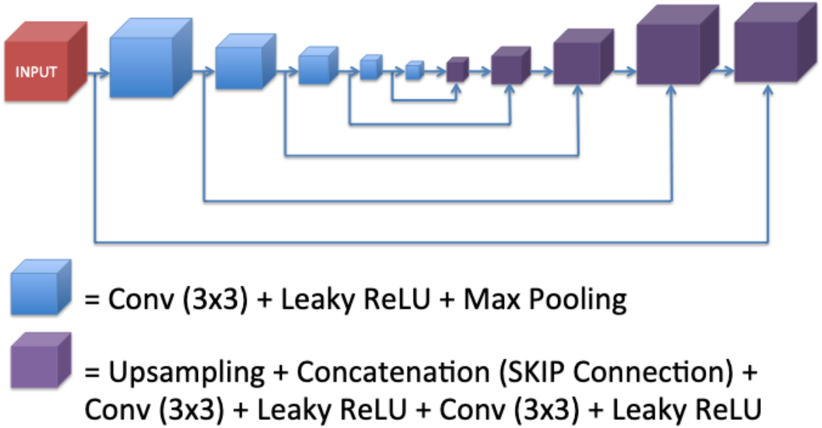
Input

Prediction

Ground Truth

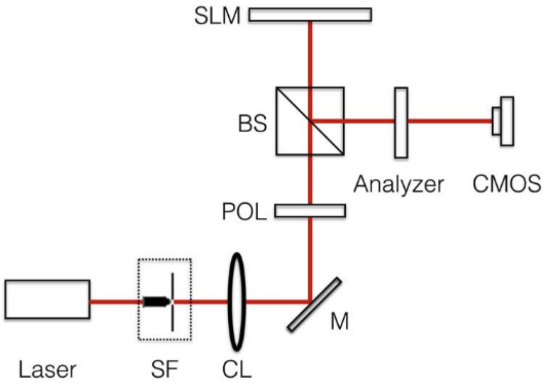
Ryoichi Horisaki, Ryosuke Takagi, and Jun Tanida. *Learning-based imaging through scattering media*. Optics Express, 2016.

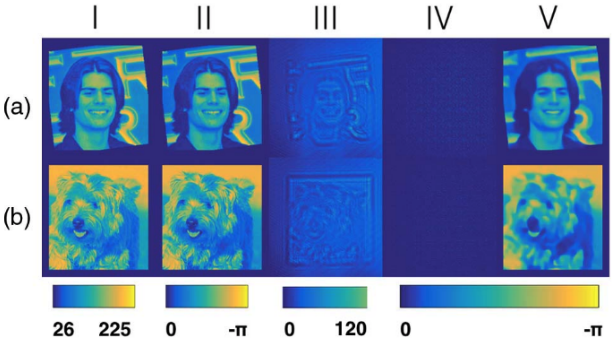
Reconstructing Intensity from Binary Spatial Gradient Cameras

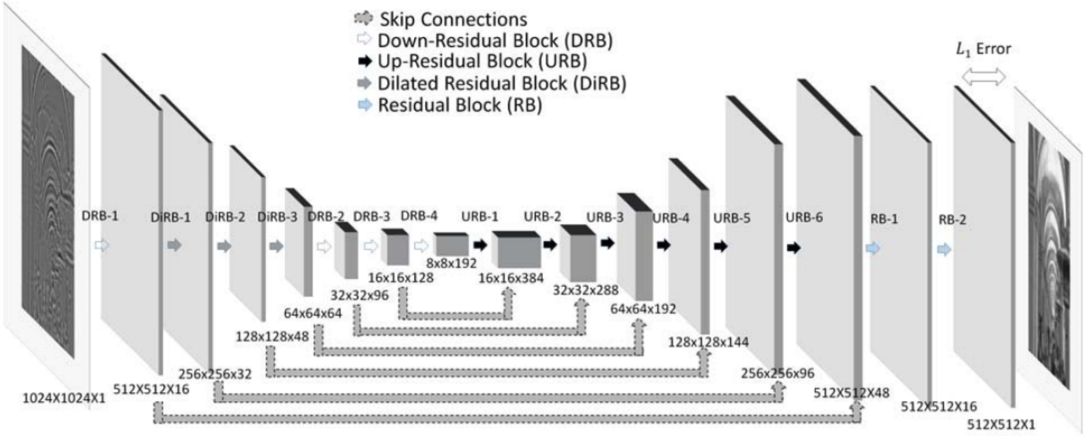


Suren Jayasuriya, Orazio Gallo, Jinwei Gu, Timo Aila, Jan Kautz. *Reconstructing Intensity Images from Binary Spatial Gradient Cameras*. CVPR, 2017.

Lensless Computational Imaging through Deep Learning

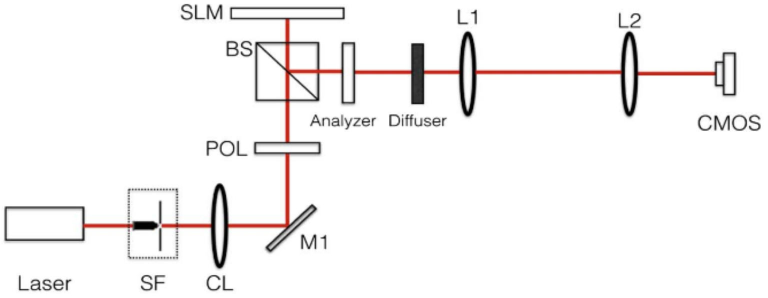


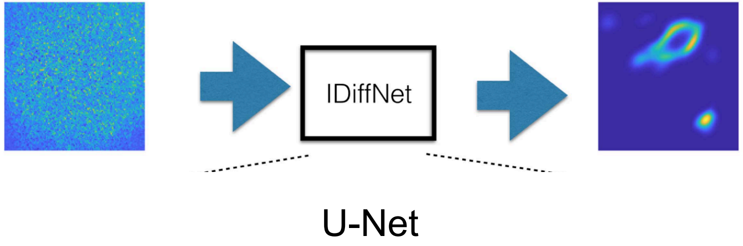


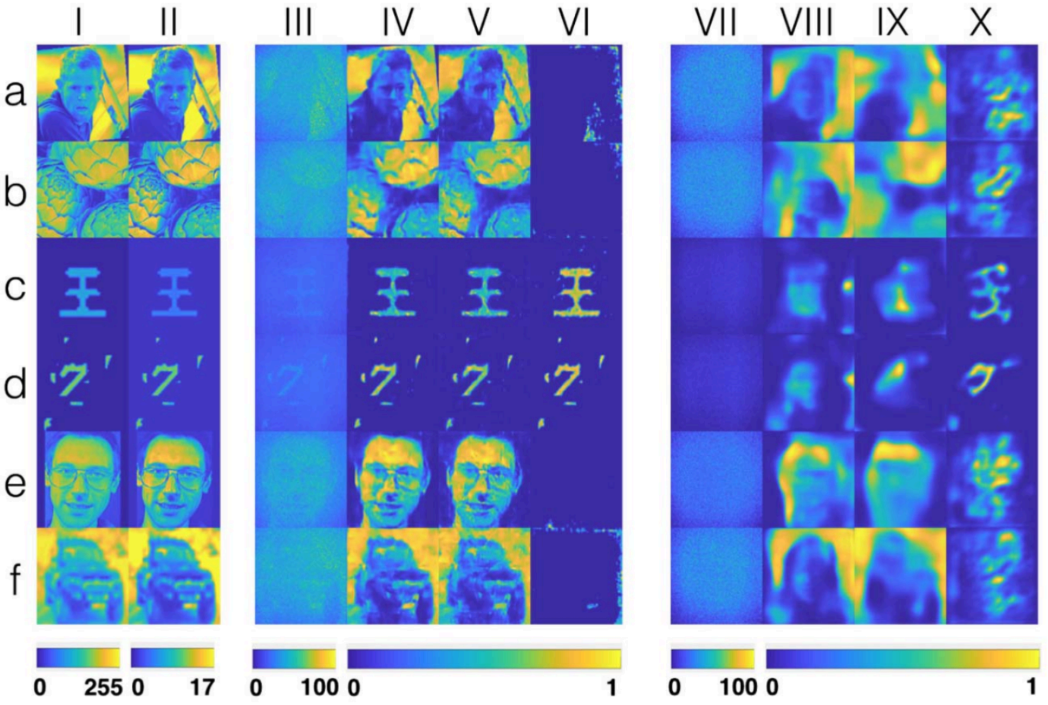


Ayan Sinha, Justin Lee, Shuai Li, and George Barbastathis. *Lensless computational imaging through deep learning*. Optica, 2017.

Imaging through glass diffusers using densely connected CNNs

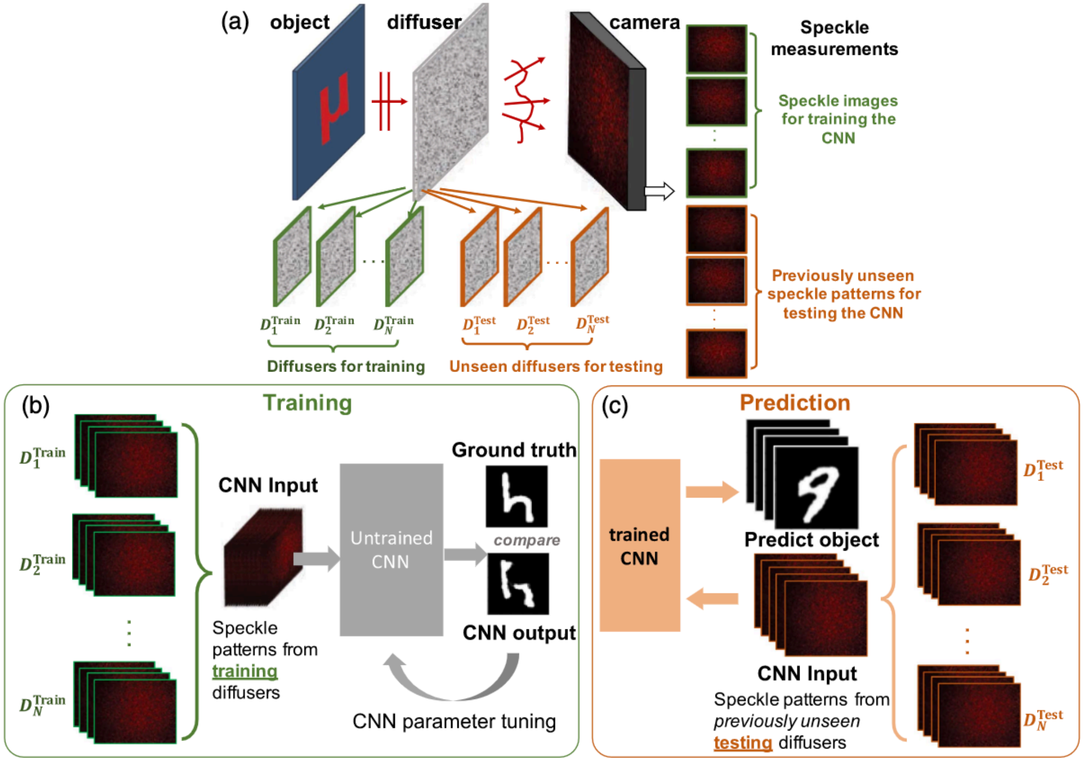


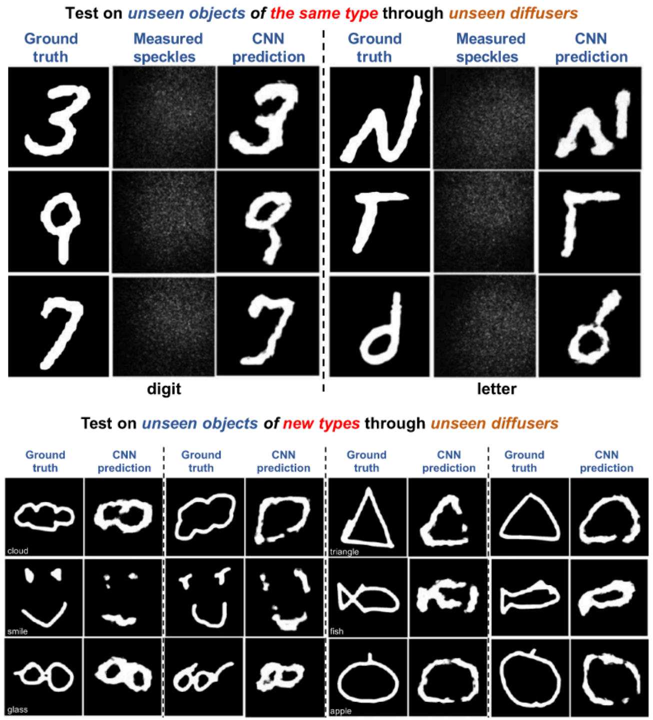




S. Li, M. Deng, J. Lee, A. Sinha, and G. Barbastathis. *Imaging through glass diffusers using densely connected convolutional neural networks*. Optica, 2018.

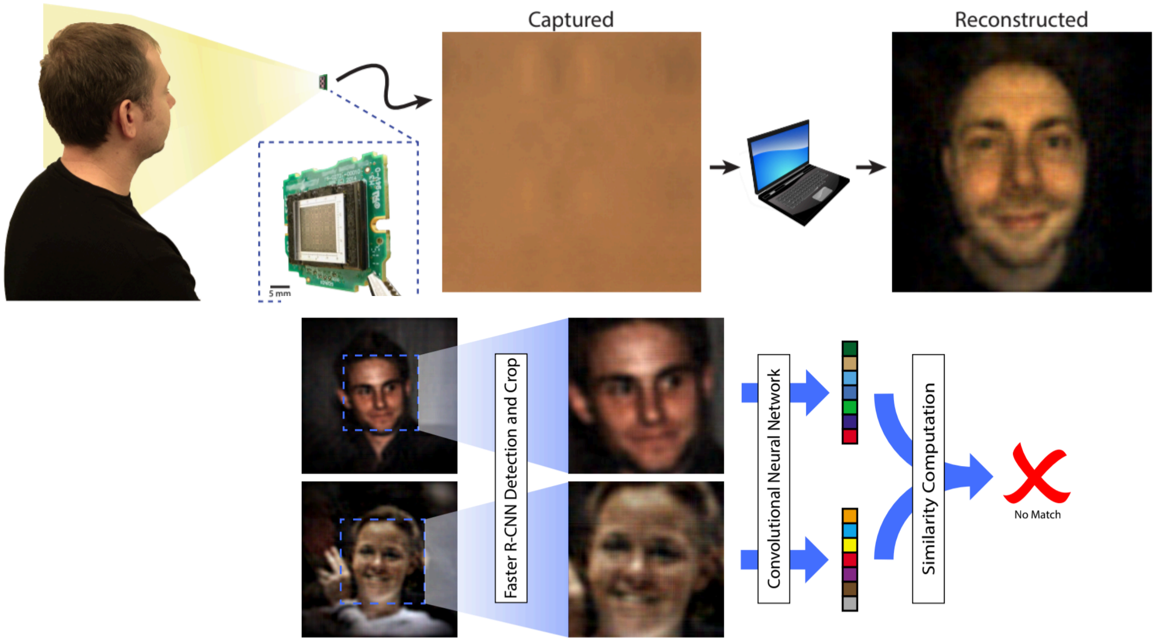
Deep speckle correlation





Y. Li, Y. Xue, L. Tian. *Deep speckle correlation: a deep learning approach toward scalable imaging through scattering media.* Optica, 2018.

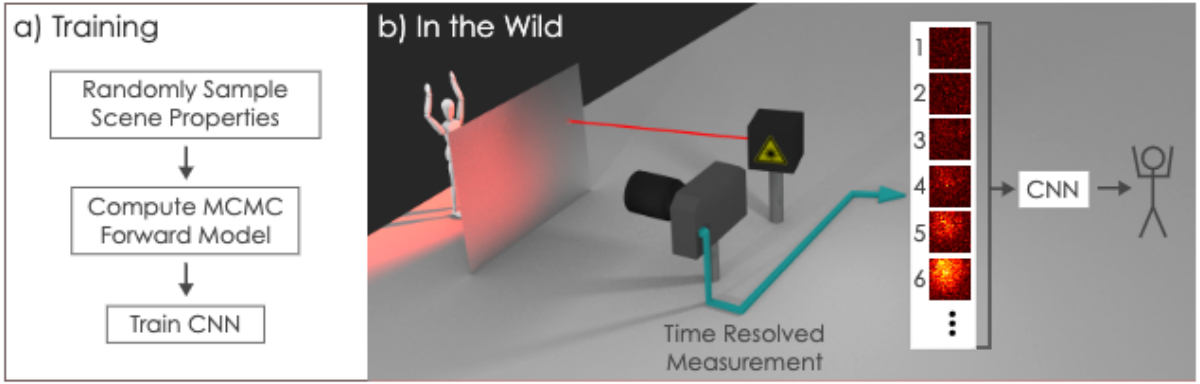
Face Detection and Verification Using Lensless Cameras

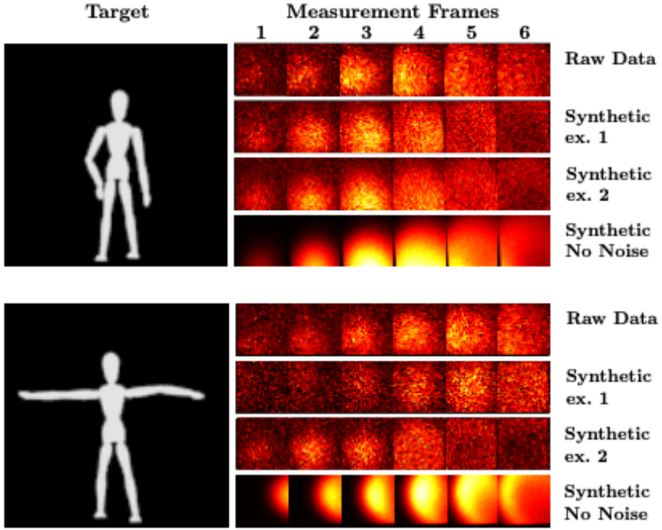


J. Tan, L. Niu, J. K. Adams, V. Boominathan, J. T. Robinson, R. G. Baraniuk, and A. Veeraraghavan. *Face Detection and Verification Using Lensless Cameras*. IEEE Trans Comp Imaging, 2018.

Non-line-of-sight

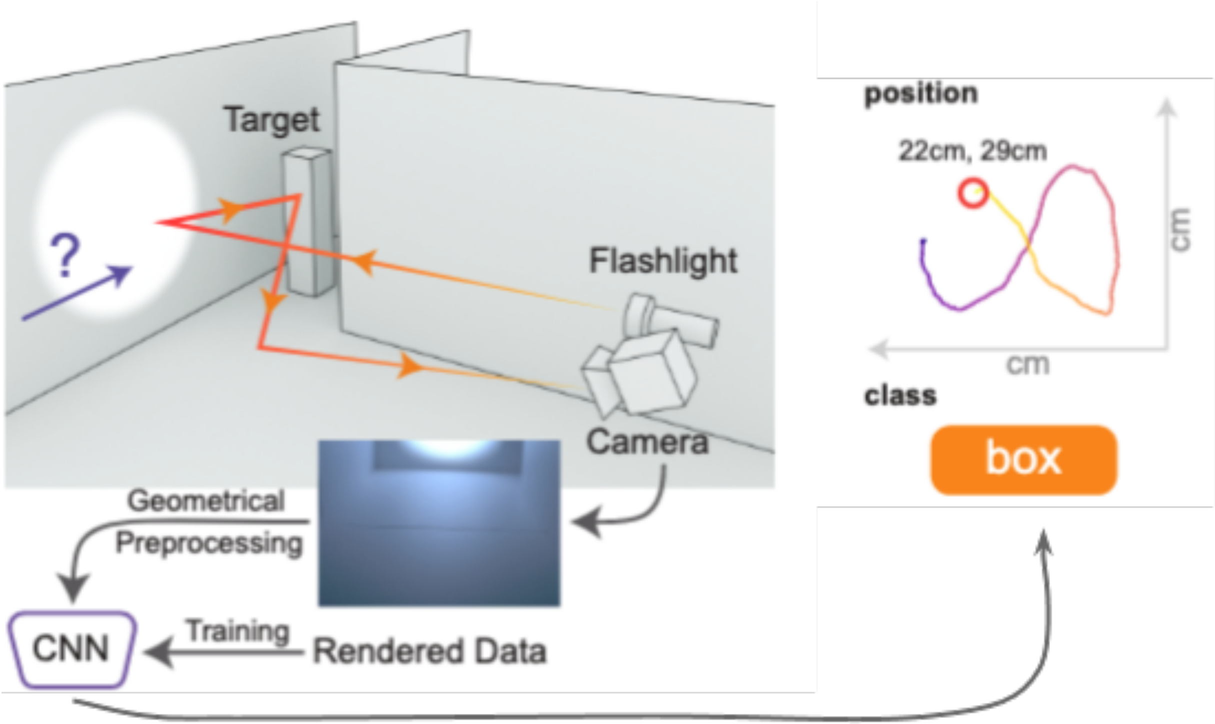
Classification through Scattering





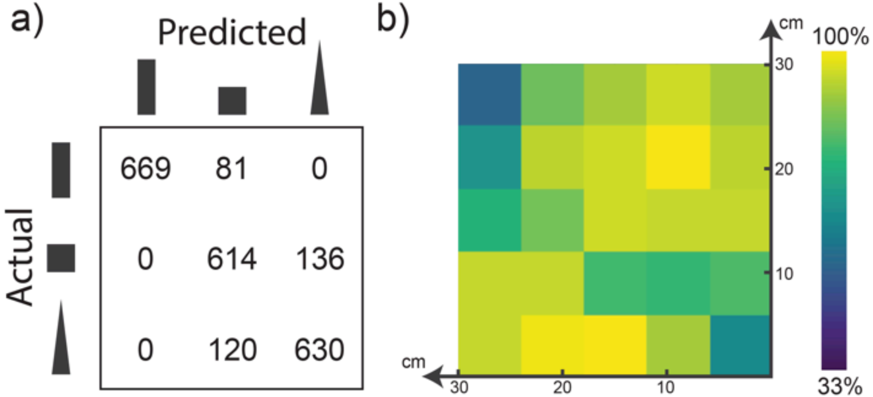
Guy Satat, Matthew Tancik, Otkrist Gupta, Barmak Heshmat, and Ramesh Raskar. *Object classification through scattering media with deep learning on time resolved measurement*. Optics Express, 2017.

Flash Photography for Data-driven Hidden Scene Recovery

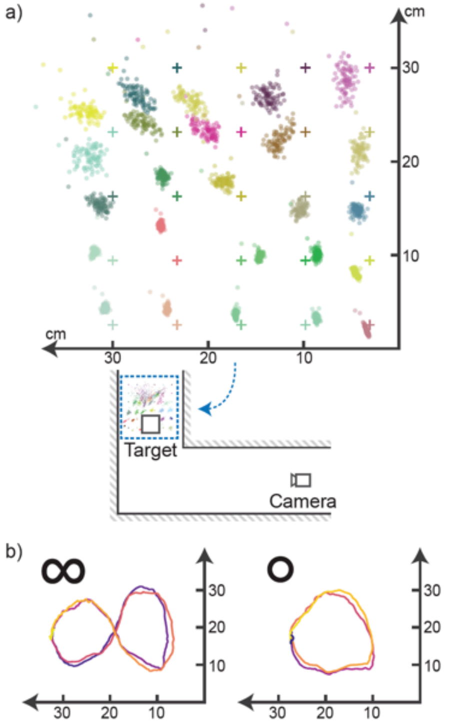


Tancik, Satat, Raskar. *Flash Photography for Data-Driven Hidden Scene Recovery*. Arxiv, 2018.

Flash Photography for Data-driven Hidden Scene Recovery



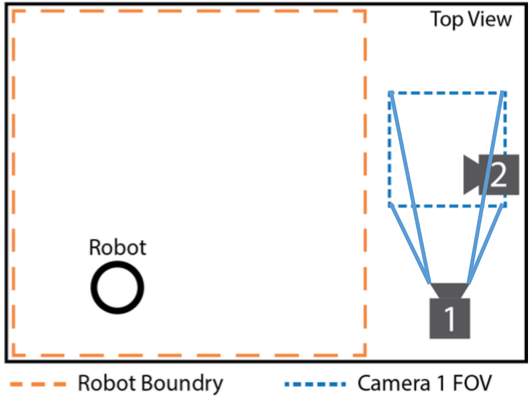
Classification

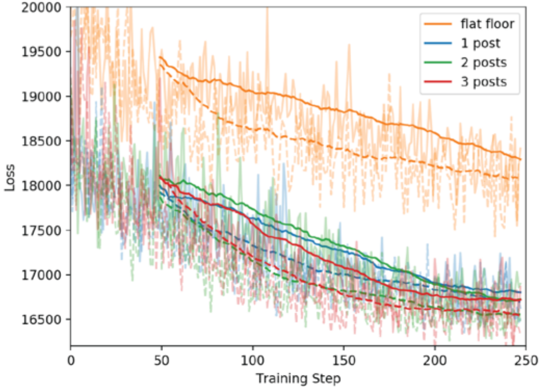


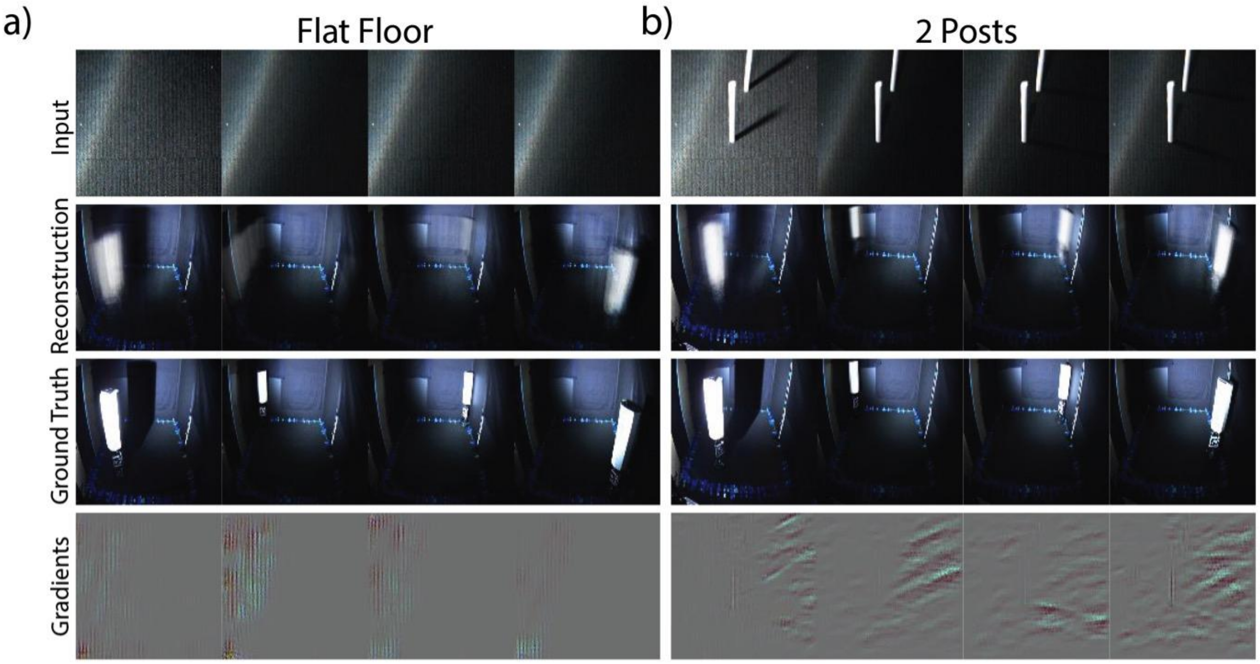
Localization

Tancik, Satat, Raskar. *Flash Photography for Data-Driven Hidden Scene Recovery*. Arxiv, 2018.

Data Driven NLOS with a Traditional Camera

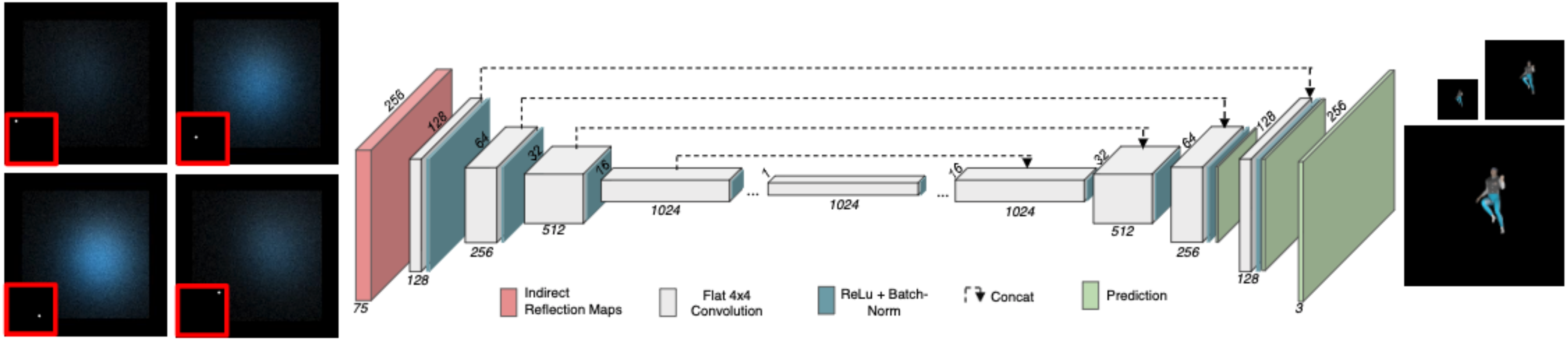






Tancik, Swedish, Satat, Raskar. *Data-Driven Non-Line-of-Sight Imaging with a Traditional Camera*. COSI, 2018.

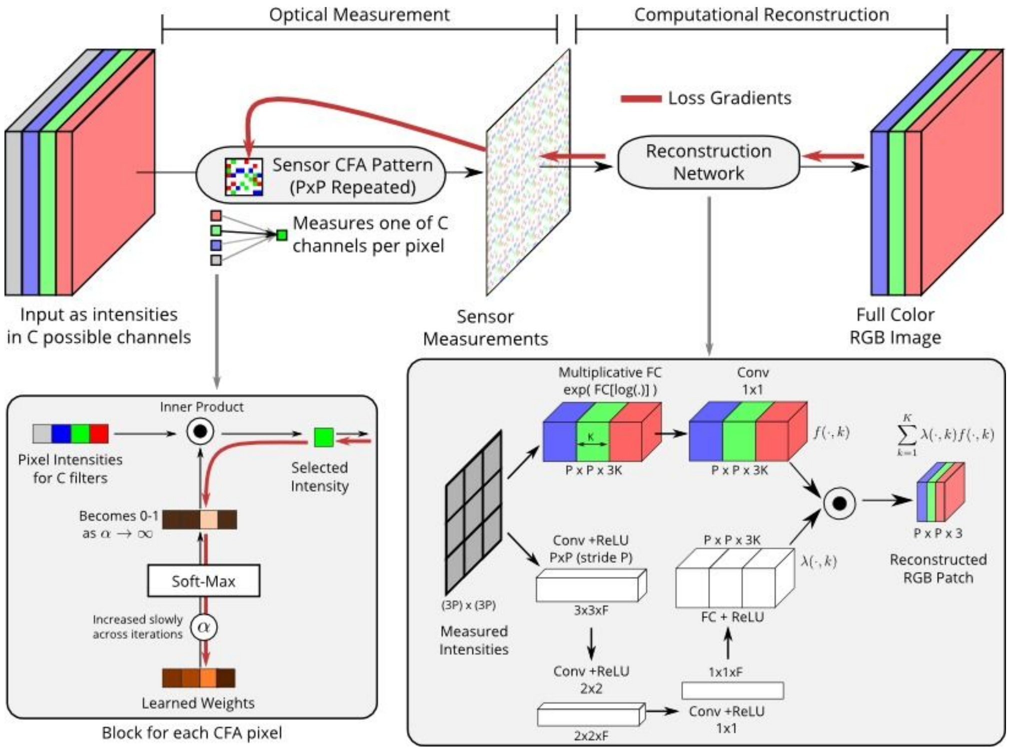
Steady State NLOS



Wenzheng Chen, Simon Daneau, Fahim Mannan, Felix Heide. *Steady-state Non-Line-of-Sight Imaging*. CVPR, 2019.

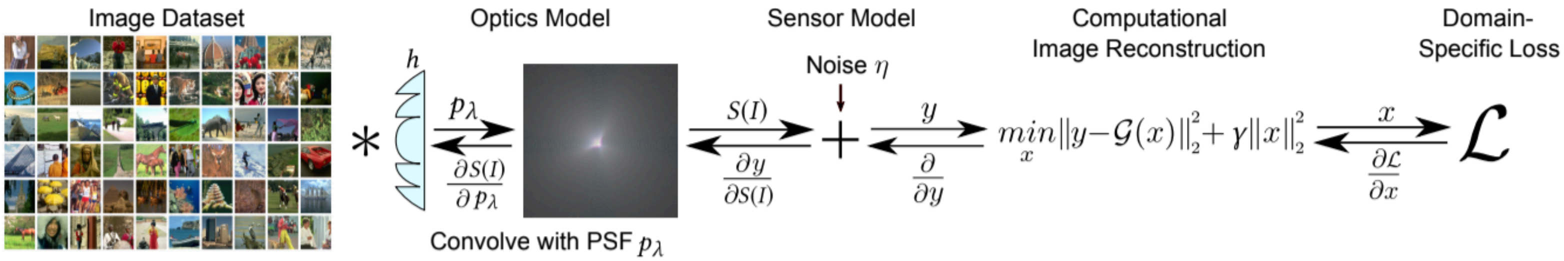
Imaging System Design

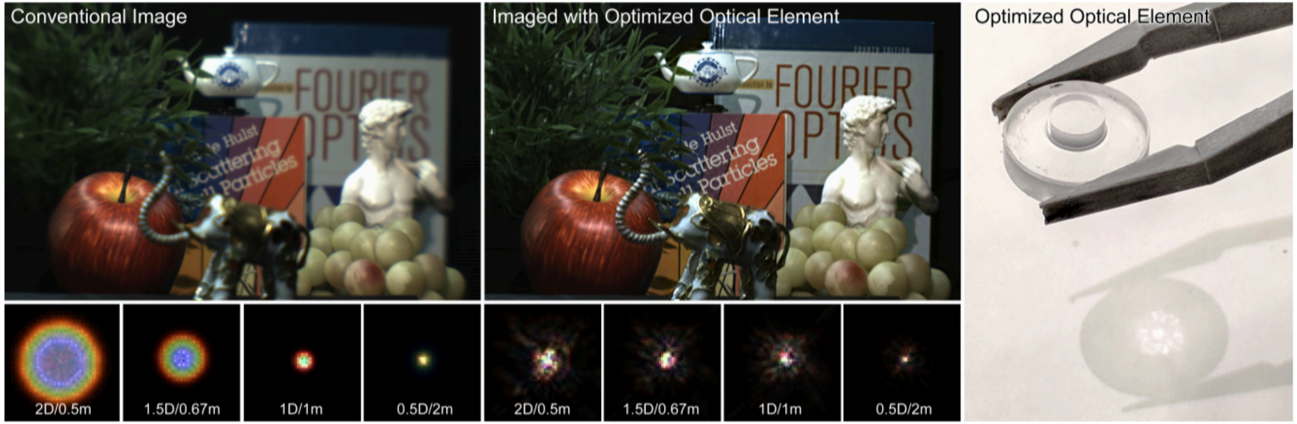
Learning Sensor Multiplexing Design through Back-propagation



Ayan Chakrabarti. *Learning Sensor Multiplexing Design through Back-propagation*. NIPS, 2016.

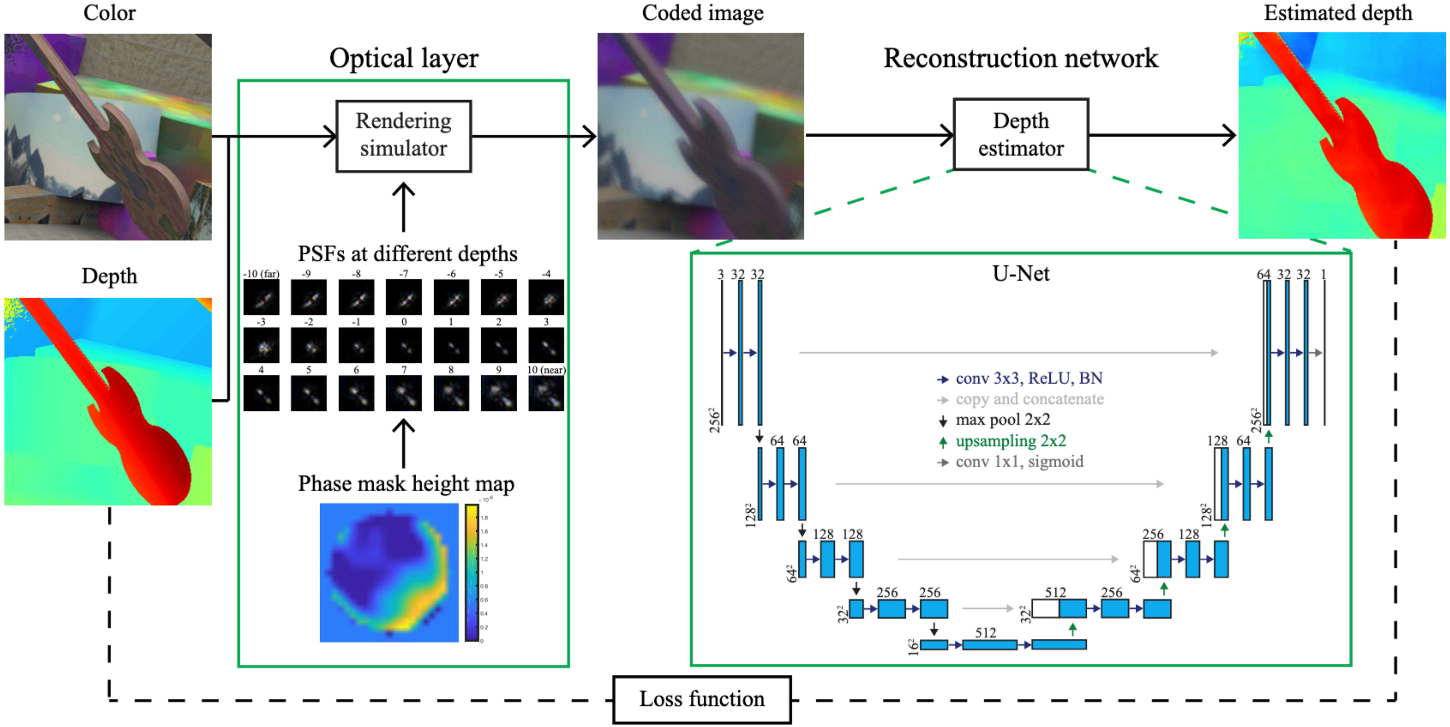
Achromatic Extended Depth of Field and Super-resolution Imaging





V. Sitzmann, S. Diamond, Y. Peng, X, Dun, S. Boyd, W. Heidrich, F. Heide, G. Wetzstein. *End-to-end Optimization of Optics and Image Processing for Achromatic Extended Depth of Field and Super-resolution Imaging*. ACM Siggraph, 2018.

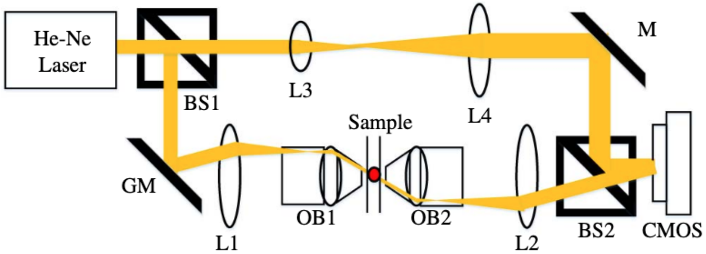
PhaseCam3D

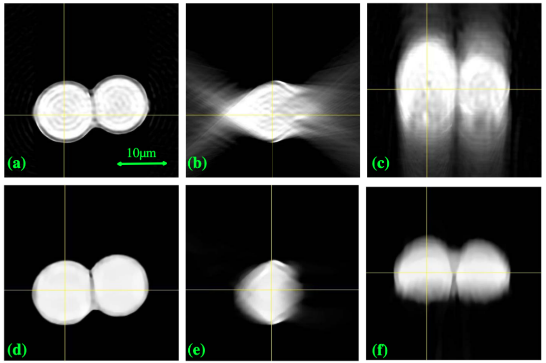


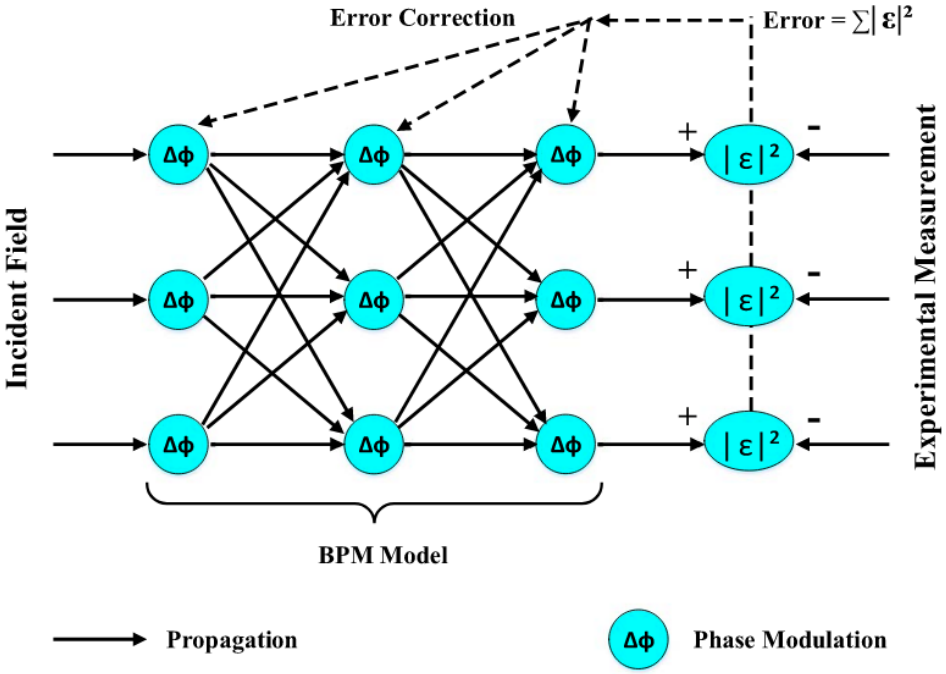
Y. Wu, V. Boominathan, H. Chen, A. Sankaranarayanan, A. Veeraraghavan. *PhaseCam3D - Learning Phase Masks for Passive Single View Depth Estimation*. ICCP, 2019.

Tomography and Deconvolution

Learning Approach to Optical Tomography

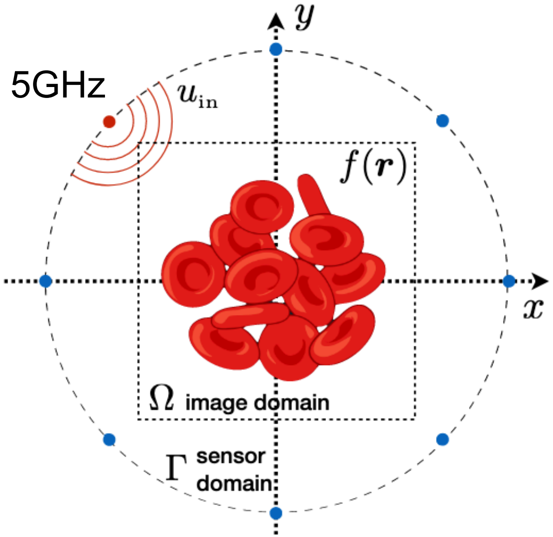




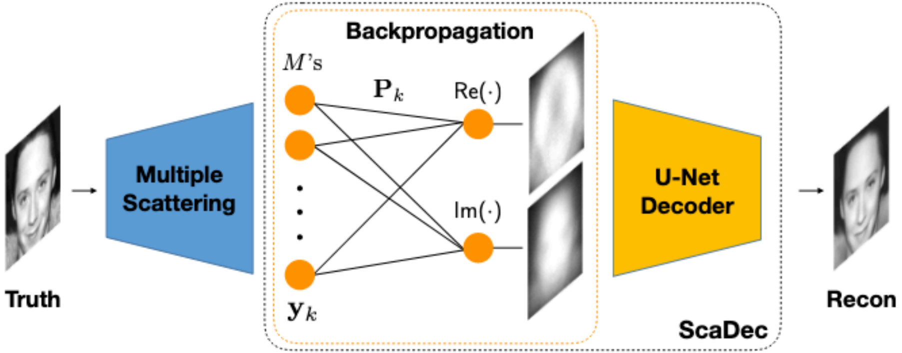


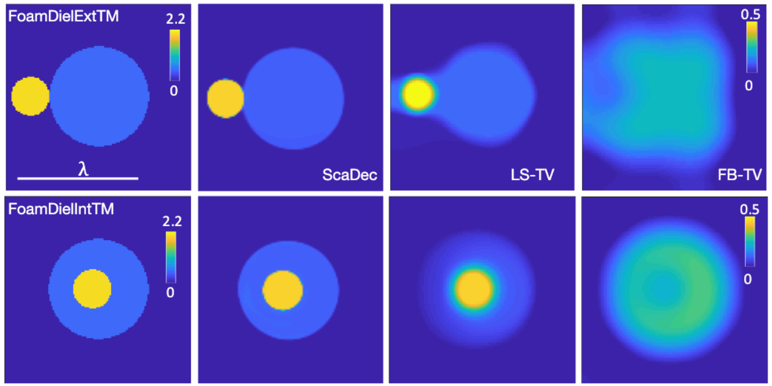
Ulugbek S. Kamilov, Ioannis N. Papadopoulos, Morteza H. Shoreh, Alexandre Goy, Cedric Vonesch, Michael Unser, and Demetri Psaltis. *Learning approach to optical tomography*. Optica, 2015.

Efficient and accurate inversion of multiple scattering with deep learning



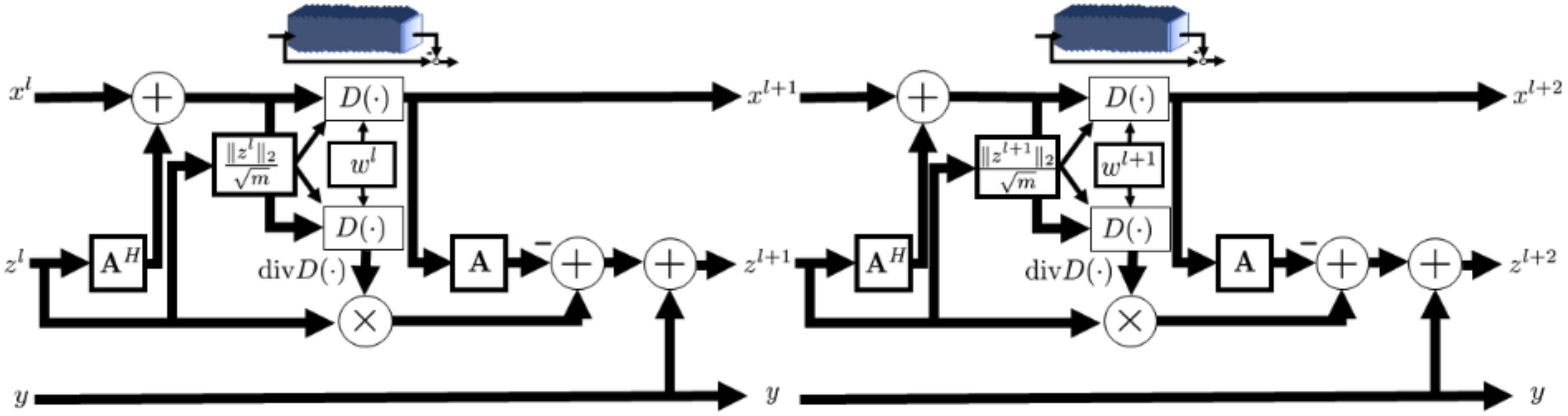
$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}\in\mathbb{R}^N} \left\{ \frac{1}{2}\|\mathbf{y} - \mathbf{H}(\mathbf{x})\|_{\ell_2}^2 + \mathcal{R}(\mathbf{x}) \right\}$$





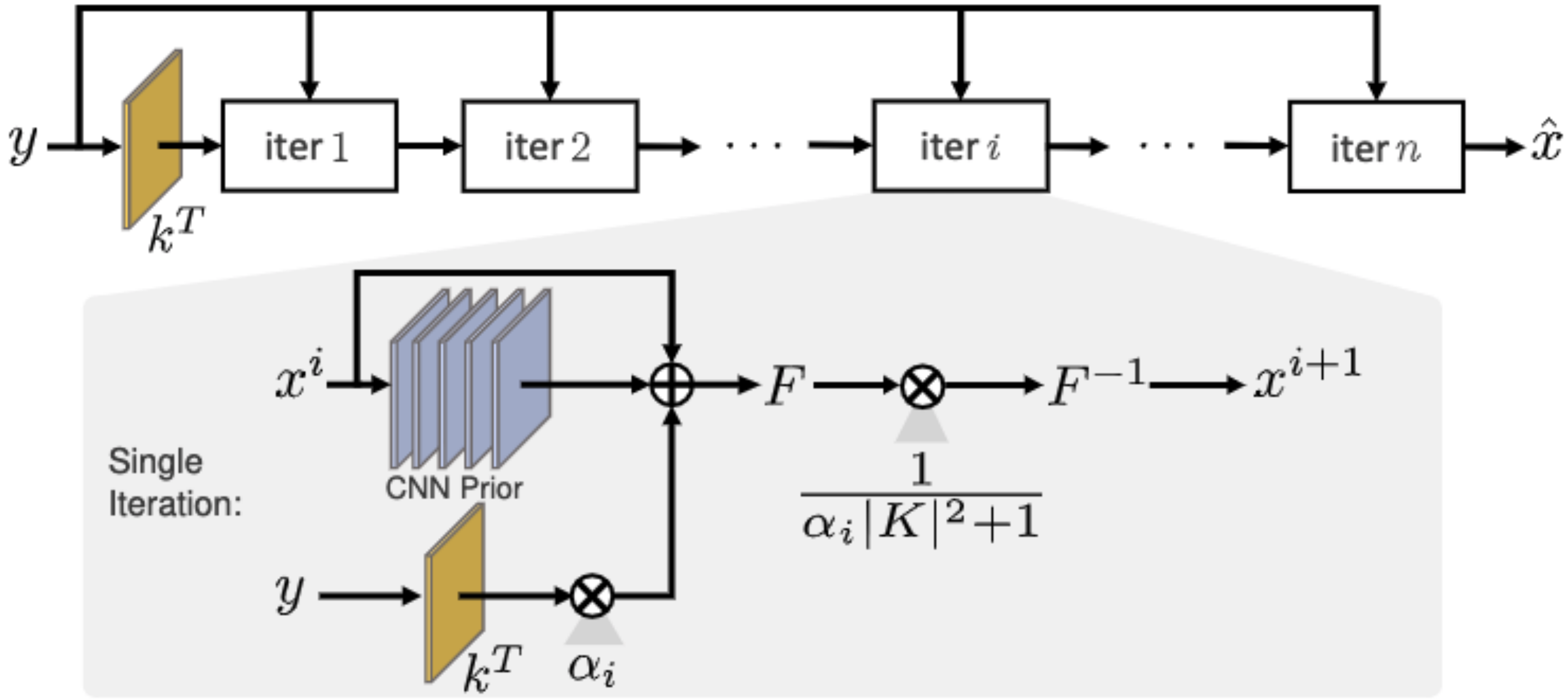
Y. Sun, Z. Xia, U. S. Kamilov. *Efficient and accurate inversion of multiple scattering with deep learning*. Optics Express, 2018.

Unrolled Optimization: Learned D-AMP



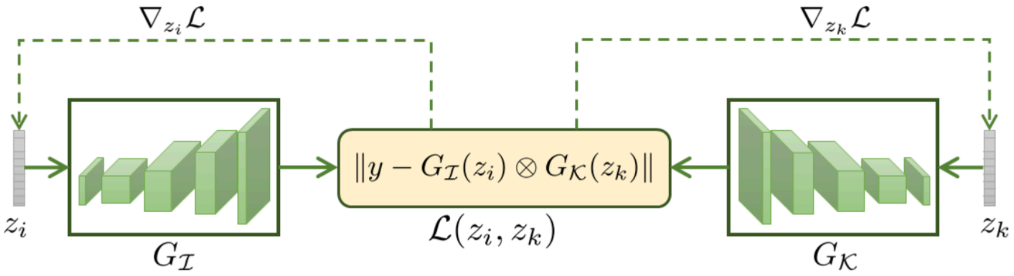
C. A. Metzler, A. Mousavi, R. G. Baraniuk, *Learned D-AMP: Principled Neural Network based Compressive Image Recovery*. NIPS, 2017.

Unrolled Optimization: Deep Priors



Steven Diamond, Vincent Sitzmann, Felix Heide, Gordon Wetzstein, *Unrolled Optimization with Deep Priors*. Arxiv, 2017/2018.

Blind Image Deconvolution using Deep Generative Priors



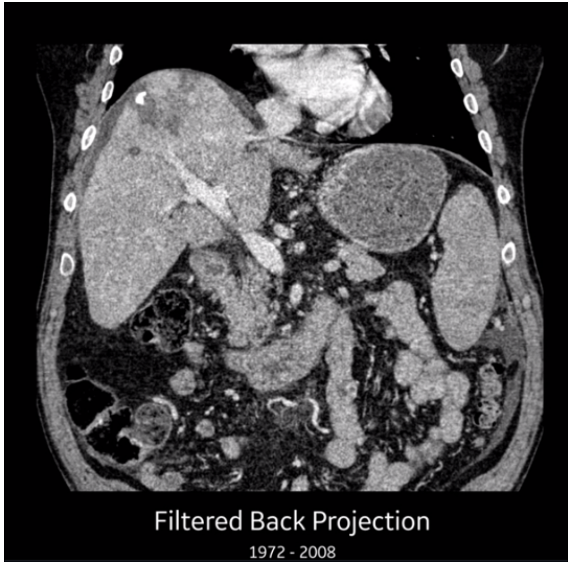
$$\underset{i, z_i, z_k}{\operatorname{argmin}} \|y - i \otimes G_{\mathcal{K}}(z_k)\|^2 + \tau \|i - G_{\mathcal{I}}(z_i)\|^2 + \zeta \|y - G_{\mathcal{I}}(z_i) \otimes G_{\mathcal{K}}(z_k)\|^2 + \rho \|i\|_{\text{tv}}.$$

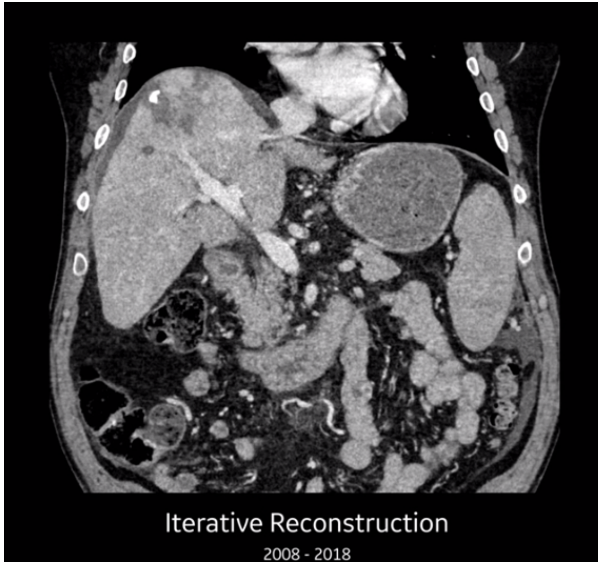
M. Asim, F. Shamshad, A. Ahmed. *Blind Image Deconvolution using Deep Generative Priors.* Arxiv, 2019.

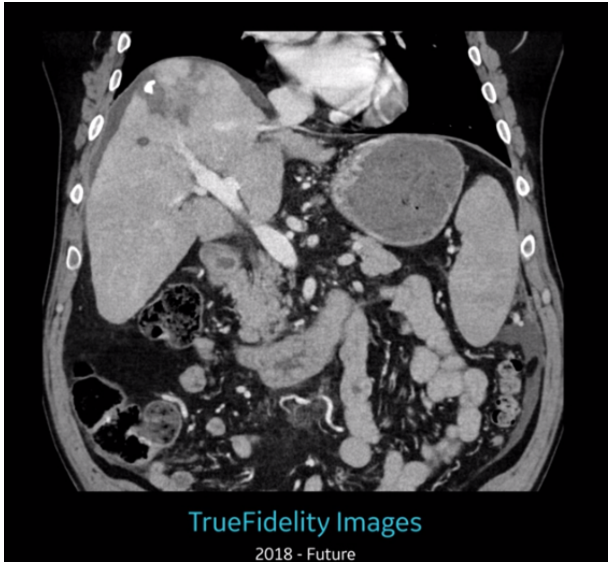
See Also: Paul Hand and Vladislav Voroninski. *Global Guarantees for Enforcing Deep Generative Priors by Empirical Risk*. Proceedings of Conf. On Learning Theory, PMLR, 2018.

GE APEX CT

Deep Learning Image Reconstruction: Cleared by FDA in April 2019

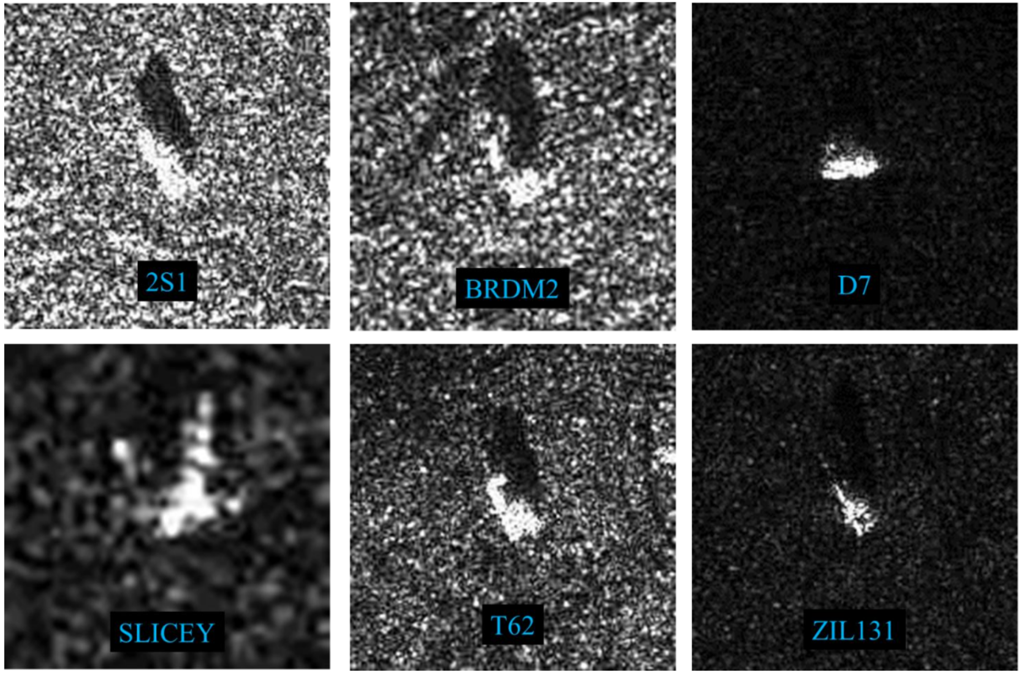






https://www.gehealthcare.com/en-GB/products/computed-tomography/revolution-apex

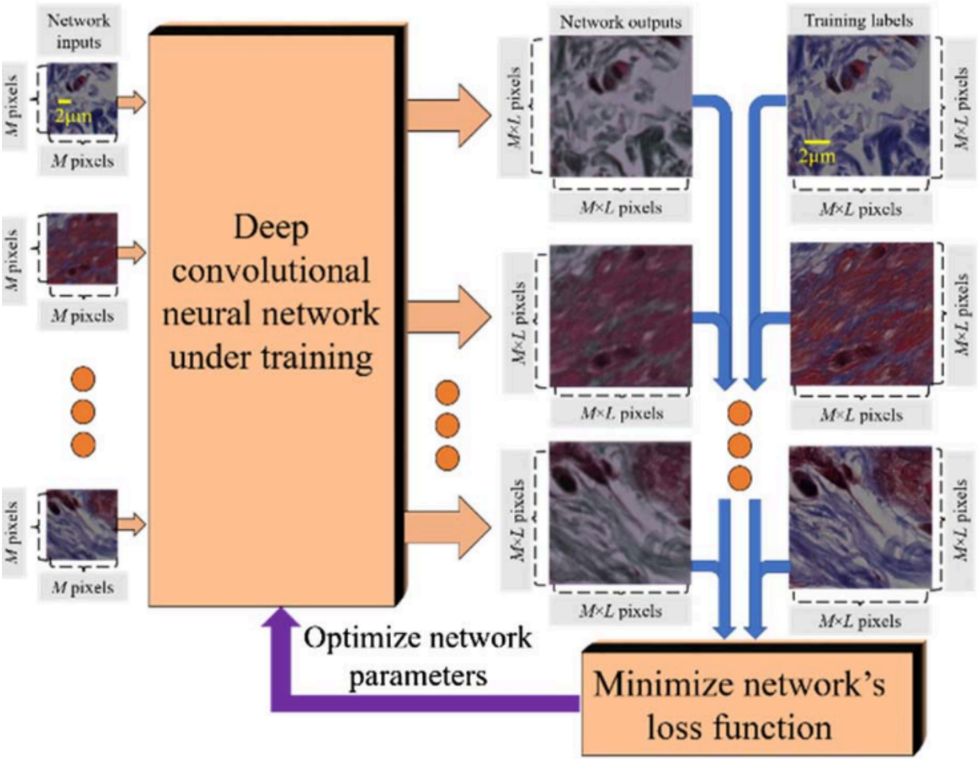
Convolutional neural networks for synthetic aperture radar classification



Andrew Profeta, Andres Rodriguez, H. Scott Clouse. *Convolutional neural networks for synthetic aperture radar classification*. Proc. SPIE 9843, Algorithms for Synthetic Aperture Radar Imagery XXIII, 2016.

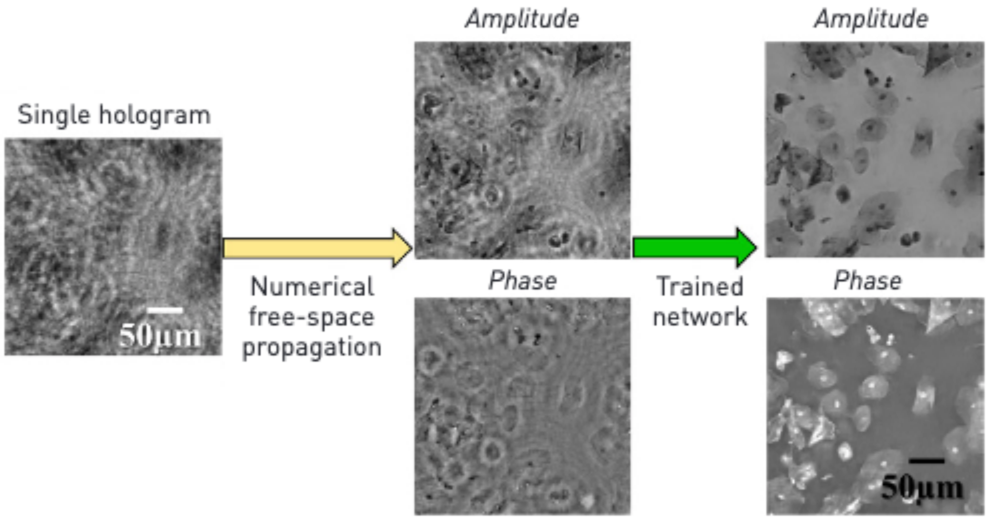
Microscopy

Deep learning microscopy



Y. Rivenson, Z. Gorocs, H. Gunaydin, Y. Zhang, H. Wang, and A. Ozcan. *Deep Learning Microscopy*. Optica, 2017.

Towards a Thinking Microscope



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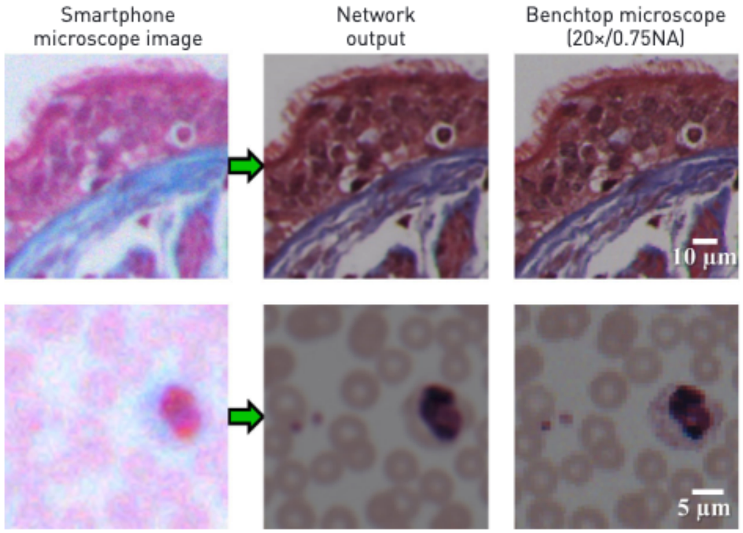
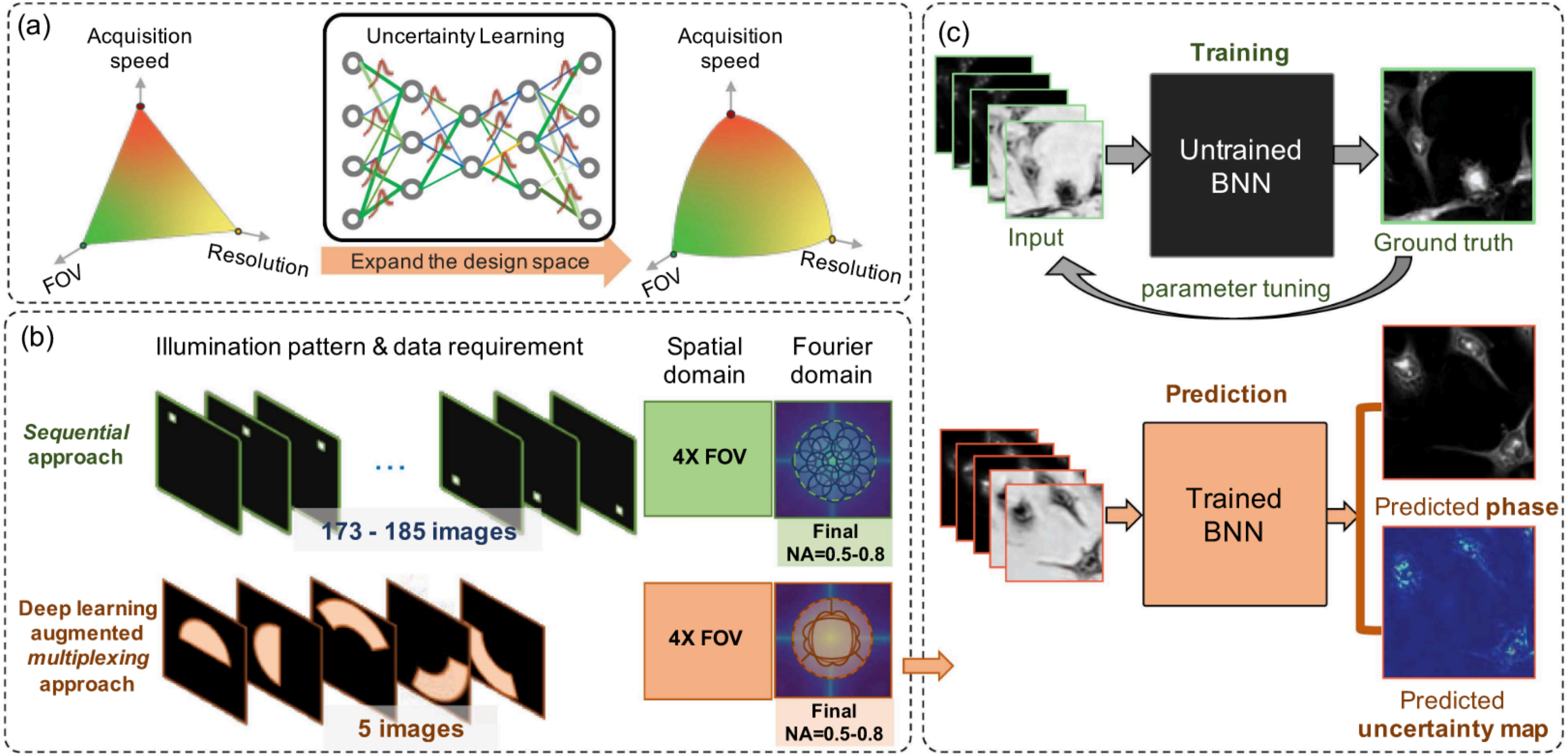


(b)

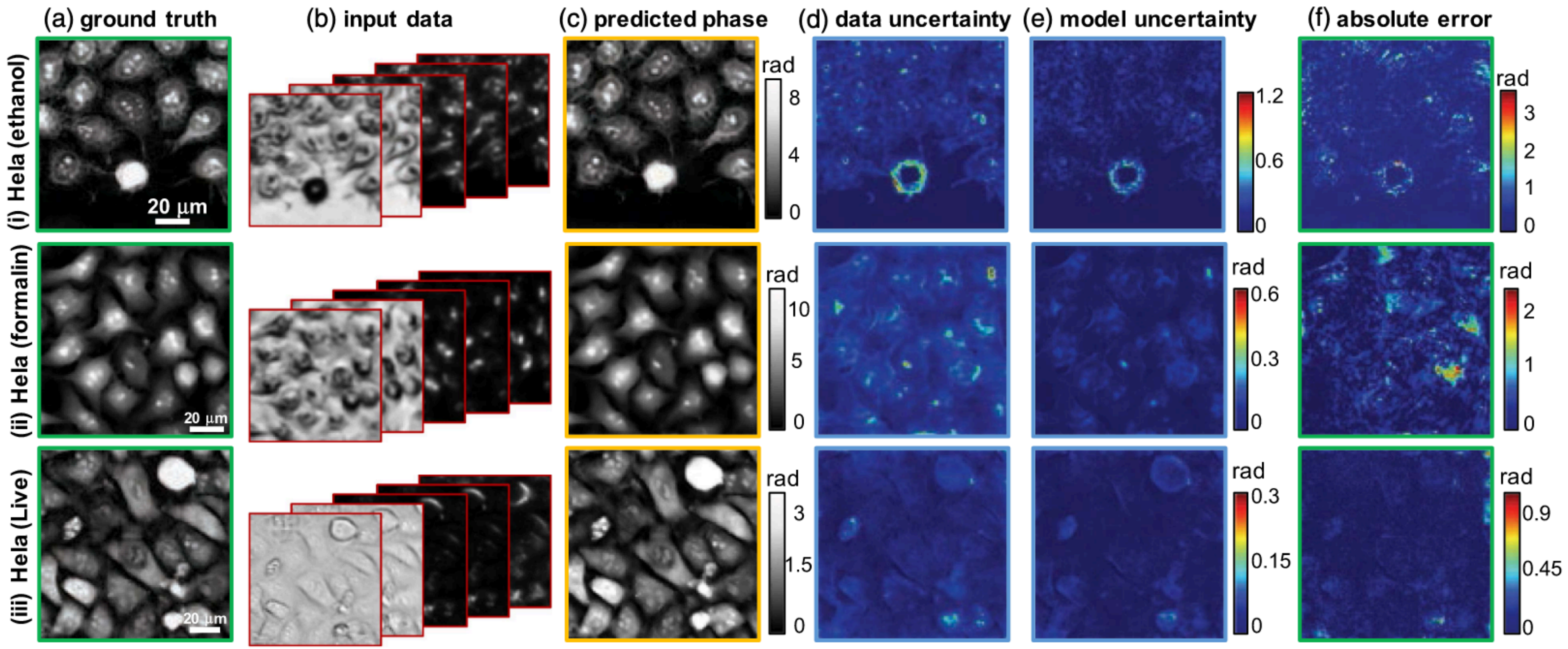
Y. Rivenson and A. Ozcan. *Toward a Thinking Microscope: Deep Learning in Optical Microscopy and Image Reconstruction*. OSA OPN , 2018.

Reliable deep-learning-based phase imaging with uncertainty quantification



Y. Xue, S. Cheng, Y. Li, L. Tian. *Reliable deep-learning-based phase imaging with uncertainty quantification*. Optica, 2019.

Reliable deep-learning-based phase imaging with uncertainty quantification



Y. Xue, S. Cheng, Y. Li, L. Tian. *Reliable deep-learning-based phase imaging with uncertainty quantification*. Optica, 2019.

Summary

- Moving beyond pure classification problems
- U-net is very popular architecture
- “Hybrid” iterative methods using learning is an emerging field
- Still difficult to demonstrate generalization across different optical setups
    - Calibration to synthetic training data still required
    - Training data collected on same instrument as test device

Summary

Computational Imaging is Diverse:

- Low-level Processing (Denoising and Demosaicking)
- 3D Imaging
- **Lensless, Speckle, Scattering**
- **Non-line-of-sight**
- **Imaging System Design**
- Tomography and Deconvolution
- Microscopy