Jeffrey A. Fessler

EECS Department, BME Department, Dept. of Radiology
University of Michigan

http://web.eecs.umich.edu/~fessler

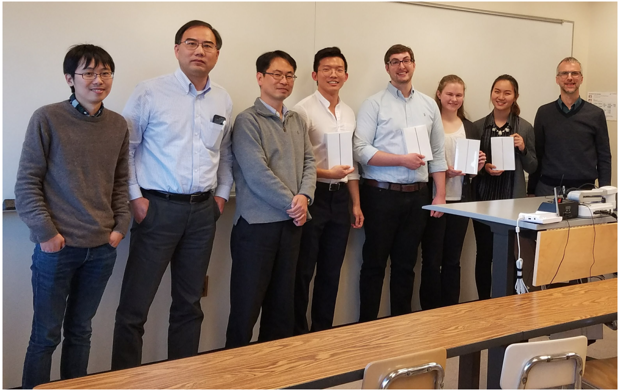
KLA visit
2019-10-03

Bio

- 1985 BS EE Purdue
- 1990 PhD EE Stanford (X-ray imaging)
- Michigan ...
- Computational imaging: PET, SPECT, X-ray CT, polarimetry, MRI, denoising, confocal microscopy restoration, X-ray tomosynthesis, light-field imaging...
- 2006 IEEE Fellow
- 2016 William L. Root Collegiate Professorship
- 59 past PhD students (ECE, BME, Appl. Math., Appl. Phys.)
- 11 current PhD students, 5 undergrads, 1 postdoc, 1 visiting PhD
- 13 patents awarded, 6 licensed
- Teaching: signal and image processing, matrix methods, optimization, ...

KLA connections

- Two former PhD students work(ed) at KLA: Hung Nien, Feng Zhao (RAPID)
  PhD dissertation committee for Yong Zhang
- 2010 consulting for KLA(-Tencor) on multi-modality image registration
- Graduate image processing course (EECS 556) group projects (many years)

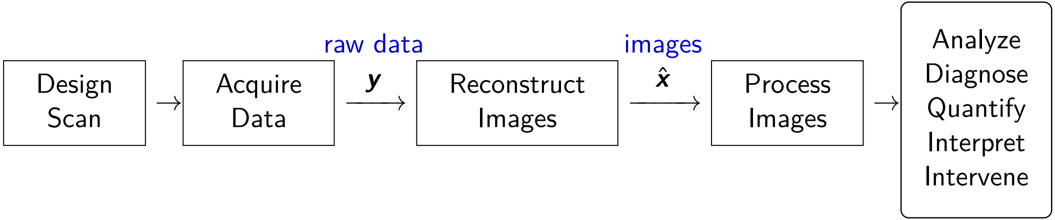


Winter 2018

Jing Zhang, Yong Zhang, Sean Park, Sang, Alex, Caroline, Rebecca ...

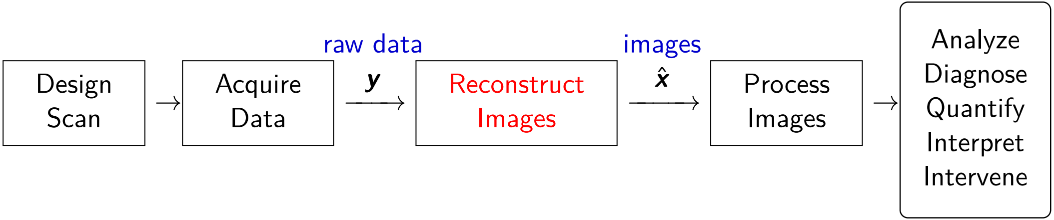
Imaging overview

J. Fessler



Imaging overview

J. Fessler

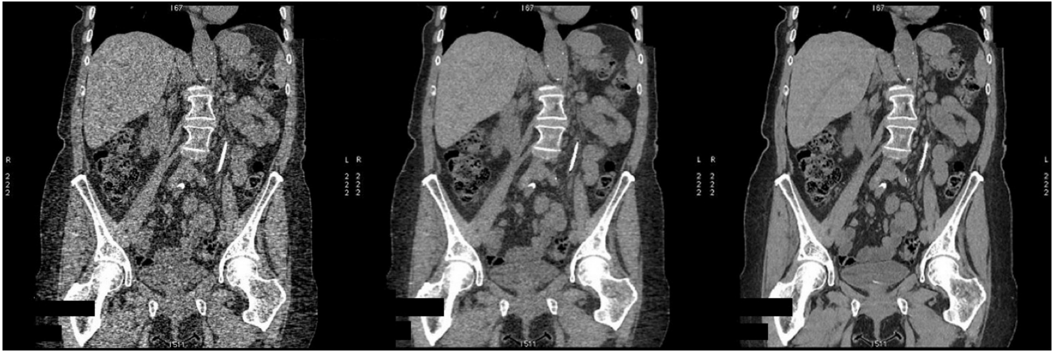


Model-based image reconstruction (MBIR)

$$\hat{\boldsymbol{x}} = \arg\min_{\boldsymbol{x}} \frac{1}{2} \|\boldsymbol{A}\boldsymbol{x} - \boldsymbol{y}\|_2^2 + \beta R(\boldsymbol{x}), \quad \boldsymbol{A}: \text{ system physics}, \; R: \text{ regularizer/prior}$$

Model-based image reconstruction in X-ray CT

J. Fessler

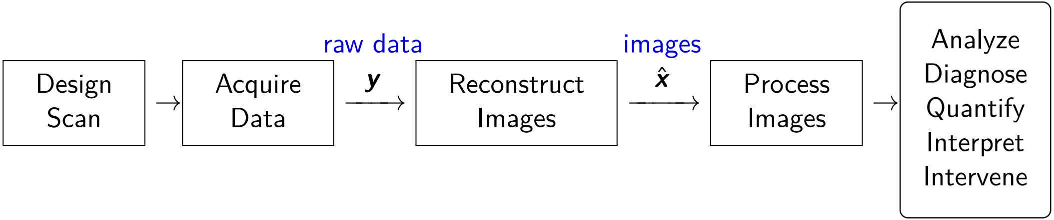


Thin-slice FBP | Denoising | MBIR

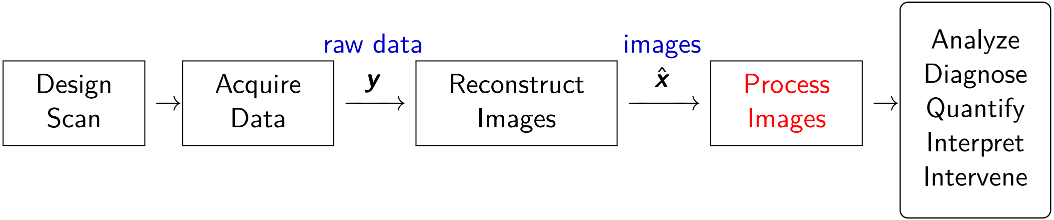
MBIR approved by FDA circa 2012 [1]

Machine learning in imaging

J. Fessler

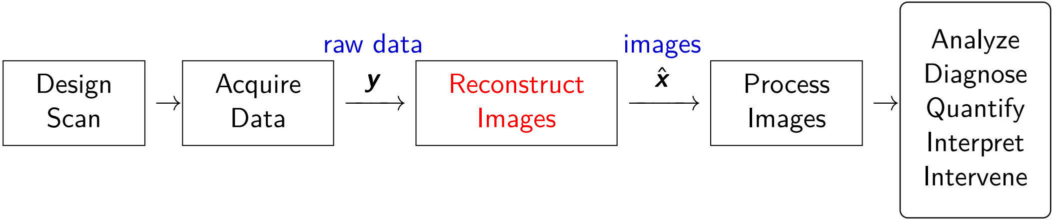


Machine learning in imaging



Most obvious place for machine learning

Special issue of IEEE Trans. on Med. Imaging in May 2016 [2].



Another (initially less obvious?) place for machine learning

June 2018 special issue of IEEE Trans. on Medical Imaging [3]:

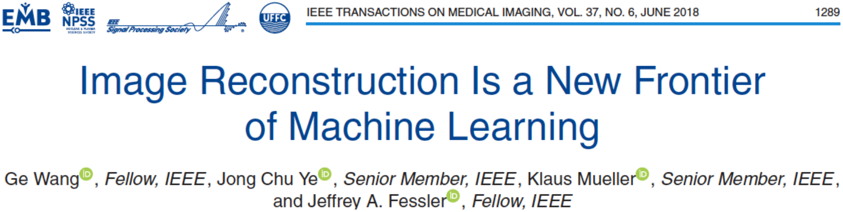
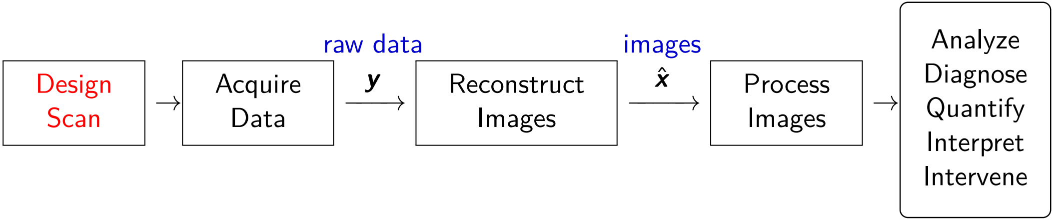

IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 37, NO. 6, JUNE 2018 1289

Image Reconstruction Is a New Frontier of Machine Learning

Ge Wang, *Fellow, IEEE*, Jong Chu Ye, *Senior Member, IEEE*, Klaus Mueller, *Senior Member, IEEE*, and Jeffrey A. Fessler, *Fellow, IEEE*

Machine learning in imaging



Data-driven methods for acquisition design

Emerging topic in MRI [4–9]

Outline

Cost function for convolutional sparsity regularization:

$$\arg\min_{\boldsymbol{x}} \frac{1}{2} \|\boldsymbol{A}\boldsymbol{x} - \boldsymbol{y}\|_{\boldsymbol{W}}^2 + \beta \left(\min_{\zeta} \sum_{k=1}^{K} \frac{1}{2} \|\boldsymbol{h}_k * \boldsymbol{x} - \zeta_k\|_2^2 + \alpha \|\zeta_k\|_1 \right)$$

Alternating minimization updates:

$$\text{Sparse code:} \qquad \zeta_k^{(n+1)} = \mathrm{soft}\{\boldsymbol{h}_k * \boldsymbol{x}^{(n)}, \alpha\}$$

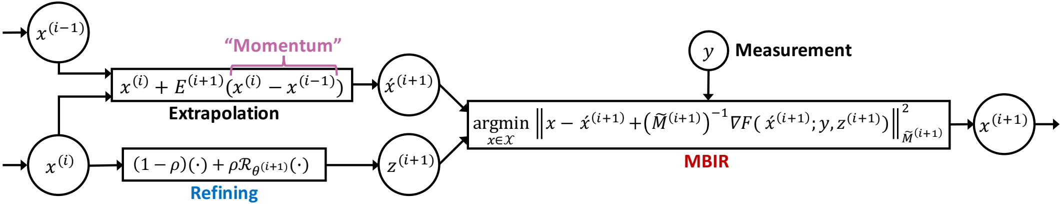
$$\text{Image:} \quad \boldsymbol{x}^{(n+1)} = \arg\min_{\boldsymbol{x}} F(\boldsymbol{x}; \boldsymbol{y}, \boldsymbol{z}^{(n)})$$

$$F(\boldsymbol{x}; \boldsymbol{y}, \boldsymbol{z}^{(n)}) \triangleq \frac{1}{2} \|\boldsymbol{A}\boldsymbol{x} - \boldsymbol{y}\|_{\boldsymbol{W}}^2 + \beta \left(\sum_{k=1}^{K} \frac{1}{2} \left\|\boldsymbol{h}_k * \boldsymbol{x} - \zeta_k^{(n+1)}\right\|_2^2 + \alpha \left\|\zeta_k^{(n+1)}\right\|_1 \right)$$

$$= \frac{1}{2} \|\boldsymbol{A}\boldsymbol{x} - \boldsymbol{y}\|_{\boldsymbol{W}}^2 + \beta \frac{1}{2} \left\|\boldsymbol{x} - \boldsymbol{z}^{(n)}\right\|_2^2 \quad \text{(quadratic but } \textit{large} \Longrightarrow \text{majorize)}$$

$$\boldsymbol{z}^{(n)} = \mathcal{R}(\boldsymbol{z}^{(n)}) = \sum_{k=1}^{K} \mathrm{flip}(\boldsymbol{h}_k) * \mathrm{soft}\{\boldsymbol{h}_k * \boldsymbol{x}^{(n)}\} \quad \text{(denoise} \Longrightarrow \text{learn)}$$

Unrolled loop network with momentum and quadratic majorizer:



- Diagonal majorizer: $\boldsymbol{M} = \text{diag}\{\boldsymbol{A}'\boldsymbol{W}\boldsymbol{A}\boldsymbol{1}\} + \beta \boldsymbol{I} \succeq \boldsymbol{A}'\boldsymbol{W}\boldsymbol{A} + \beta \boldsymbol{I}$
- Learn image mapper ("refiner") $\mathcal{R}$ from training data (supervised).
  cf CNN: filter $\rightarrow$ threshold $\rightarrow$ filter

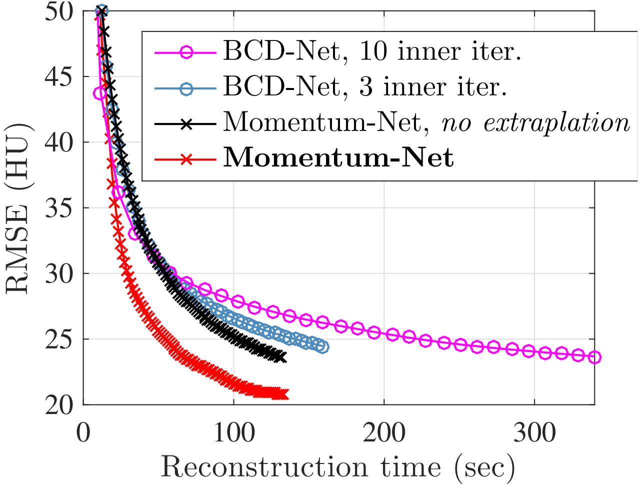
Momentum-Net benefits

- Image mapper $\mathcal{R}$ is shallow
  $\Longrightarrow$ less risk of over-fitting / hallucination
- Momentum accelerates convergence (fewer layers)
- First unrolled loop approach to have convergence theory
  (under suitable assumptions on $\mathcal{R}$)
- Image update uses original CT sinogram $\boldsymbol{y}$ and imaging physics $\boldsymbol{A}$

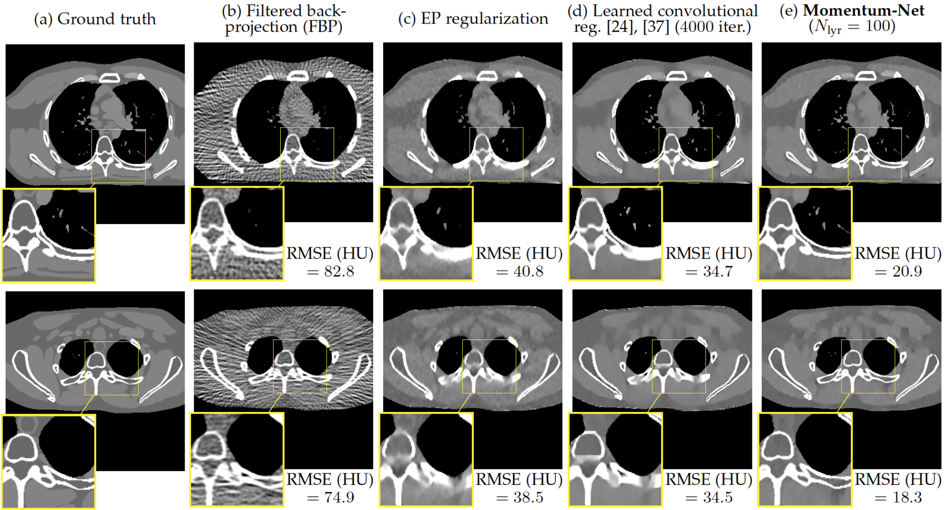
[10]
Il Yong Chun, Zhengyu Huang, Hongki Lim, J A Fessler
Momentum-Net: Fast and convergent iterative neural network for inverse problems
http://arxiv.org/abs/1907.11818

Momentum-Net preliminary results

Illustration of benefits of momentum:



Momentum-Net preliminary image results



Sparse-view CT with 123/984 views, $I_0 = 10^5$, 800-1200 mod. HU display.

Resources

Talk and code available online at
`http://web.eecs.umich.edu/~fessler`

Bibliography I

[1] P. J. Pickhardt, M. G. Lubner, D. H. Kim, J. Tang, J. A. Ruma, A. Muñoz del Rio, and G-H. Chen. "Abdominal CT with model-based iterative reconstruction (MBIR): Initial results of a prospective Trial comparing ultralow-dose with standard-dose imaging." In: *Am. J. Roentgenol.* 199.6 (Dec. 2012), 1266–74.

[2] H. Greenspan, B. van Ginneken, and R. M. Summers. "Guest editorial deep learning in medical imaging: overview and future promise of an exciting new technique." In: *IEEE Trans. Med. Imag.* 35.5 (May 2016), 1153–9.

[3] G. Wang, J. C. Ye, K. Mueller, and J. A. Fessler. "Image reconstruction is a new frontier of machine learning." In: *IEEE Trans. Med. Imag.* 37.6 (June 2018), 1289–96.

[4] Y. Cao and D. N. Levin. "Feature-recognizing MRI." In: *Mag. Res. Med.* 30.3 (Sept. 1993), 305–17.

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[6] Y. Cao and D. N. Levin. "Using an image database to constrain the acquisition and reconstruction of MR images of the human head." In: *IEEE Trans. Med. Imag.* 14.2 (June 1995), 350–61.

[7] L. Baldassarre, Y-H. Li, J. Scarlett, B. Gozcu, I. Bogunovic, and V. Cevher. "Learning-based compressive subsampling." In: *IEEE J. Sel. Top. Sig. Proc.* 10.4 (June 2016), 809–22.

[8] B. Gozcu, R. K. Mahabadi, Y-H. Li, E. Ilicak, T. Cukur, J. Scarlett, and V. Cevher. "Learning-based compressive MRI." In: *IEEE Trans. Med. Imag.* 37.6 (June 2018), 1394–406.

[9] C. D. Bahadir, A. V. Dalca, and M. R. Sabuncu. "Learning-based optimization of the under-sampling pattern in MRI." In: *Information Processing in Medical Im.* 2019, 780–92.

[10] I. Y. Chun, Z. Huang, H. Lim, and J. A. Fessler. *Momentum-Net: Fast and convergent iterative neural network for inverse problems*. 2019.