Signal processing methods for improving medical imaging

Jeff Fessler
William L Root Collegiate Professor of EECS
EECS, BME, Radiology
University of Michigan

2016-03-25

Thanks

village

Sue Cutler

Les Rogers

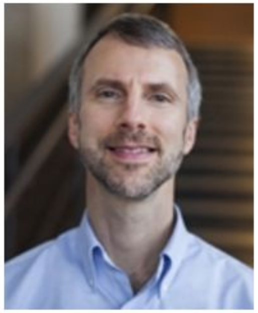
Equation lite

CSP Seminar

Inverse Problem Regularization Using Sparsity Models

Jeff Fessler

Professor
University of Michigan, Department of EECS

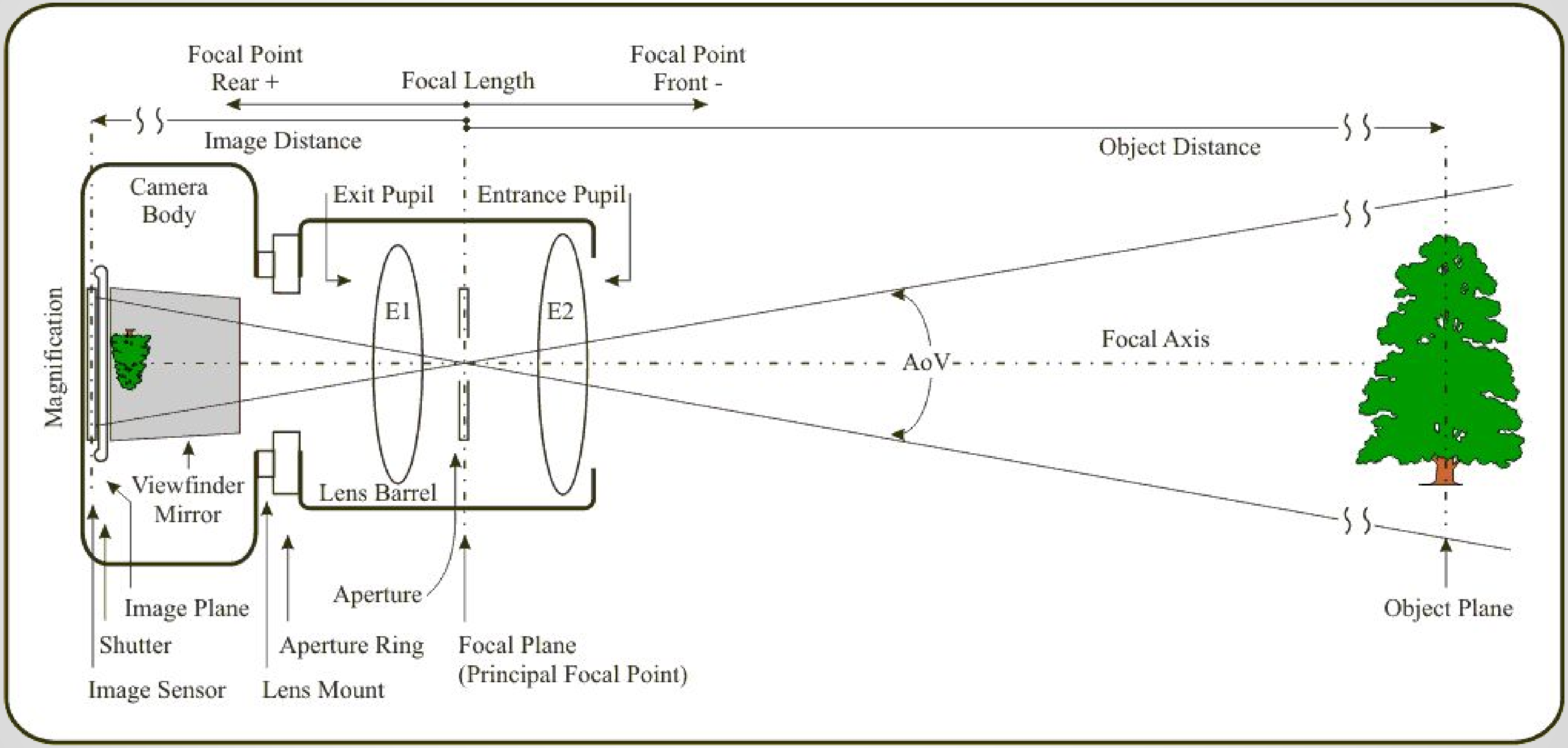


Thursday, March 31, 2016
4:00pm - 5:00pm
1005 EECS
Add to Google Calendar

About the Event

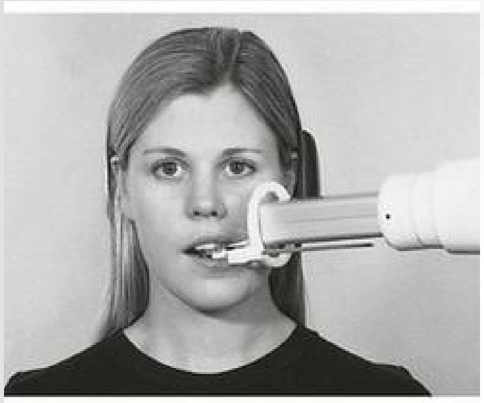
Inverse problems are usually ill-conditioned or ill-posed, meaning that there are multiple candidate solutions that all fit the measured data equally or reasonably well. Some type of prior information or modeling assumptions are needed to distinguish among candidate solutions. This talk will summarize a variety of classical and contemporary methods for regularizing inverse problems, emphasizing methods based on sparse signal models. A recent dictionary learning method that is more compute efficient than K-SVD will be highlighted as a regularizer, and used to perform sparse-view tomographic image reconstruction. The presentation will have equal parts of colorful pictures and mathematical formulas and be aimed a level suitable for students in EECS 556. Joint work with Sai Ravishankar and Raj Nadakuditi

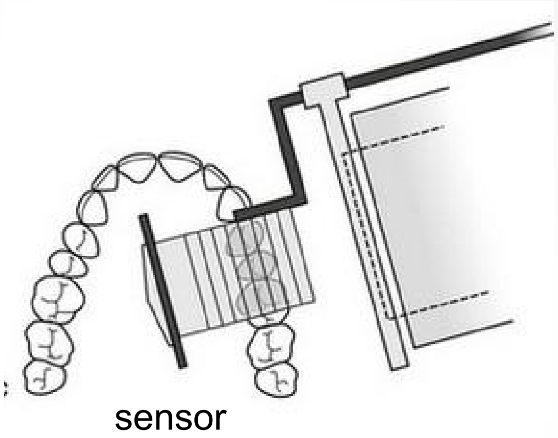
Image formation 101: cameras

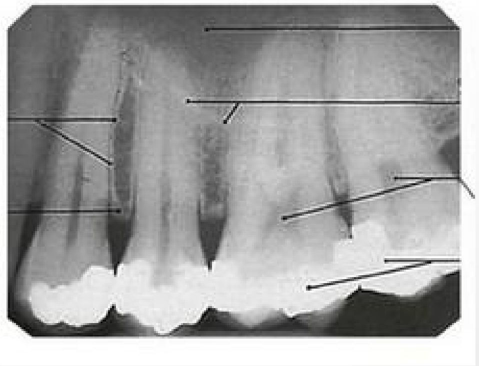


http://www.rags-int-inc.com/PhotoTechStuff/Lens101/LensDiagram_1024.gif

Image formation 102: radiography







http://pocketdentistry.com/wp-content/uploads/285/B9780702045981000079_f007-011ad-9780702045981.jpg

Image formation: CT/MRI/PET/SPECT

raw data
(physics /
engineering)

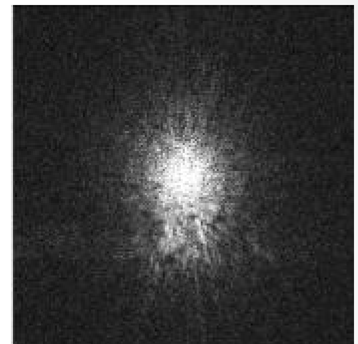


Image
reconstruction
algorithm
(math)

Final image
(medicine
/ science)

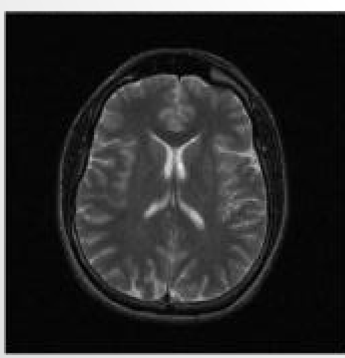
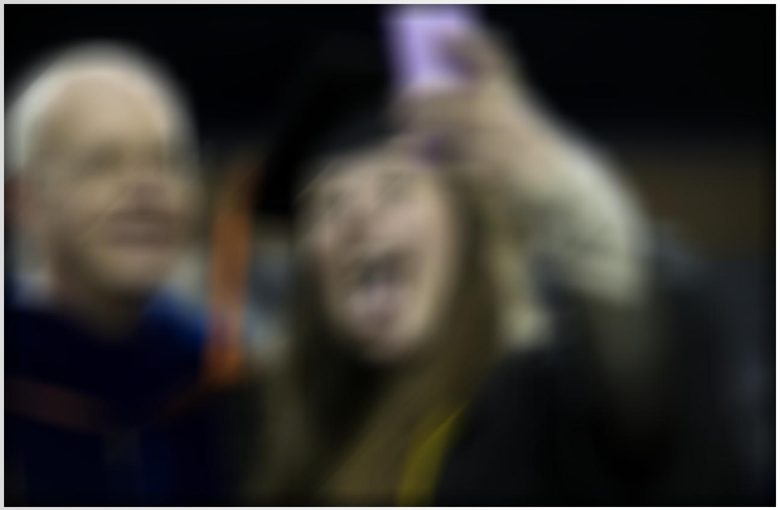


Image deblurring - an inverse problem



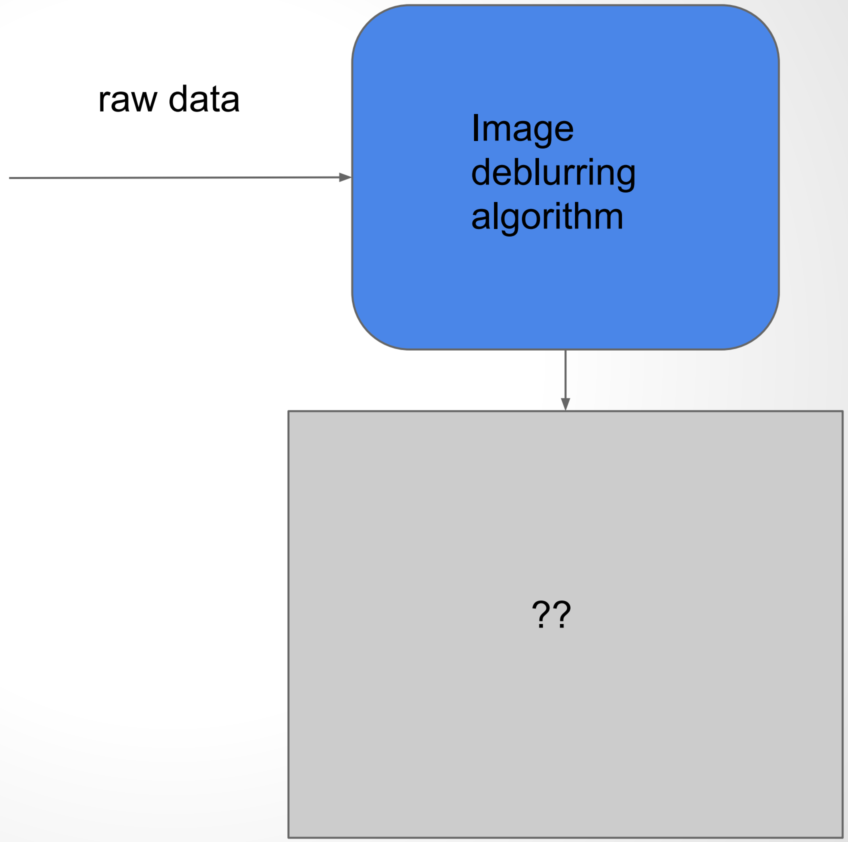
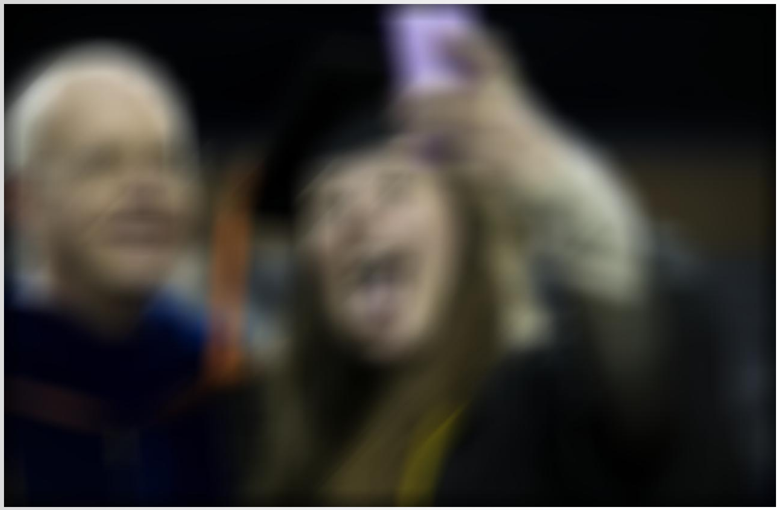
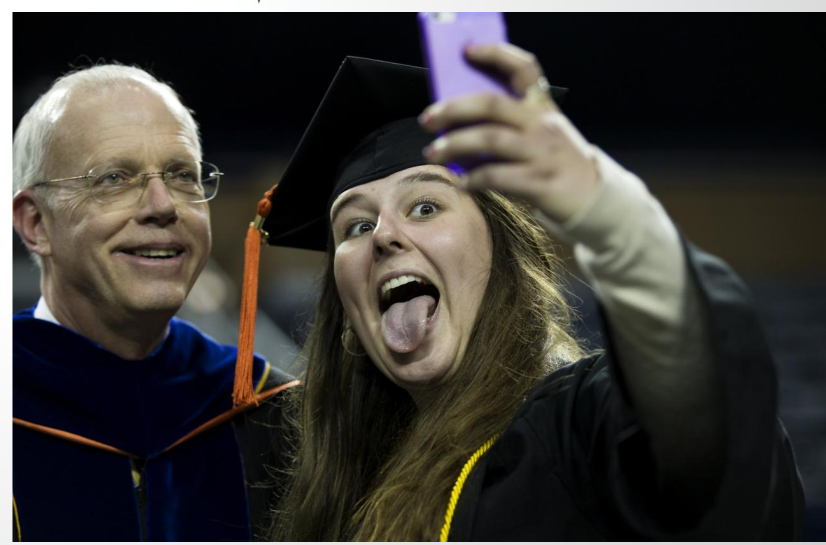


Image deblurring - an inverse problem



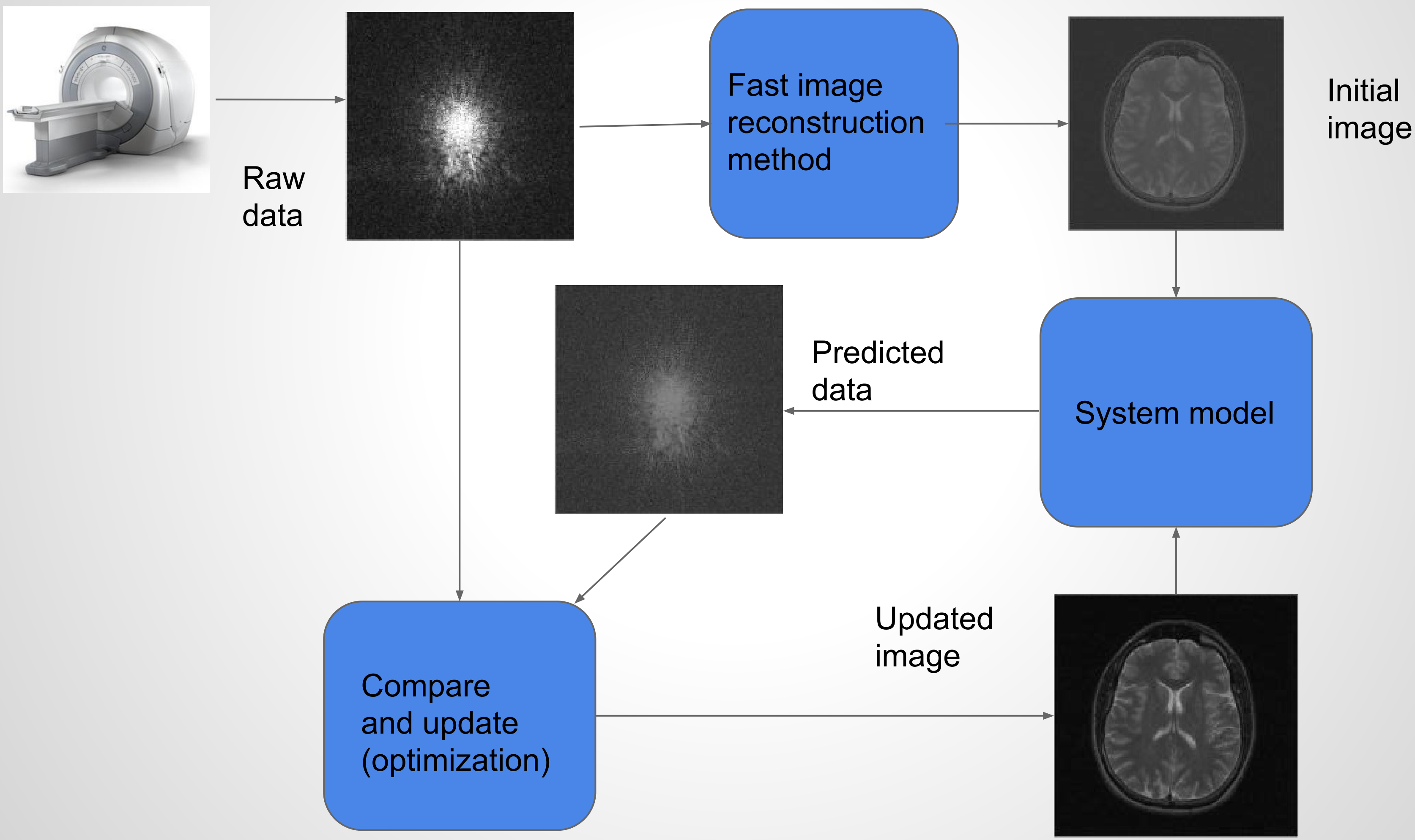
raw data

Image deblurring algorithm

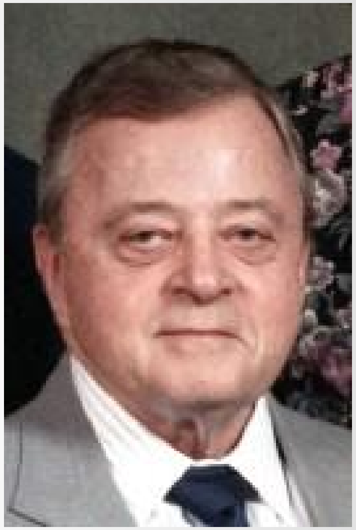


http://michiganengineering.tumblr.com/post/84680078721/a-student-takes-a-selfie-with-david-munson-jr

Iterative image reconstruction



William (Bill) Root (1919-2007)



Born 1919 in Iowa

1940 BSEE from Iowa state

1949 MSEE at MIT

1952 PhD in Math at MIT

1961 UM AERO Dept.

1986 UM EECS Dept.

1986 IEEE Shannon Award

First chair of the graduate program in computer, information, and control engineering (CICE)

http://www.lib.umich.edu/faculty-history/faculty/william-l-root

Early work on inverse problems!

Ill-posedness and precision in object-field reconstruction problems

William L. Root

Departments of Aerospace Engineering and Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, Michigan 48109

Received April 18, 1986; accepted September 9, 1986

The inherent stability or instability in reconstructing an object field, in the presence of observation noise, for a class of ill-posed problems is investigated for situations in which constraints are imposed on the object fields. The class of ill-posed problems includes inversion of truncated Fourier transforms. Two kinds of constraint are considered. It is shown that if the object field is restricted to a subset of L_2 space over R^n that is bounded, closed, convex, and has nonempty interior, then a (nonlinear) least-squares estimate always exists but is unstable. It is also shown that if one is primarily concerned with the situation in which the object field belongs to a compact parallelepiped in L_2, aligned in a natural way, there is a satisfactory, stable linear estimate that is optimal according to a min–max criterion. This also leads to a nonlinear modification for the case in which the object field is actually restricted to the parallelepiped. A summary of some relevant mathematical background is included.

Fundamental limits

Precision bounds in superresolution processing

Lawrence S. Joyce

Environmental Research Institute of Michigan, Ann Arbor, Michigan 48105

William L. Root

Department of Aerospace Engineering, The University of Michigan, Ann Arbor, Michigan 48109

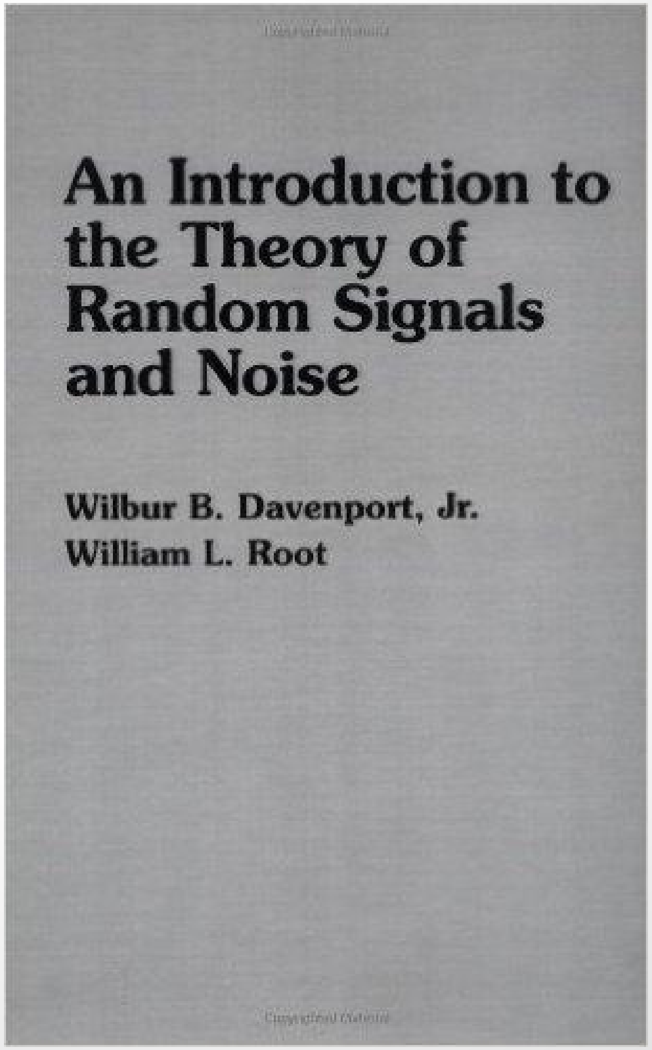
Received June 13, 1983; accepted September 26, 1983

A rather large class of problems involving the determination of an object function from observation is linear-inversion problems for which unique solutions exist but that have the property that any signal-processing algorithm designed to approximate the exact solution too precisely is unstable. This is because the problems are ill posed. The precision attainable in a class of such problems is treated here abstractly in terms of a concept called a linear-precision gauge, which essentially involves an ordered family of linear estimators. Fundamental properties of linear-precision gauges are demonstrated and discussed. A major portion of the paper is given over to applying the linear-precision gauge concept and results to Fourier imaging problems that can occur, for example, in radar and tomography.

Books

1958

McGraw Hill

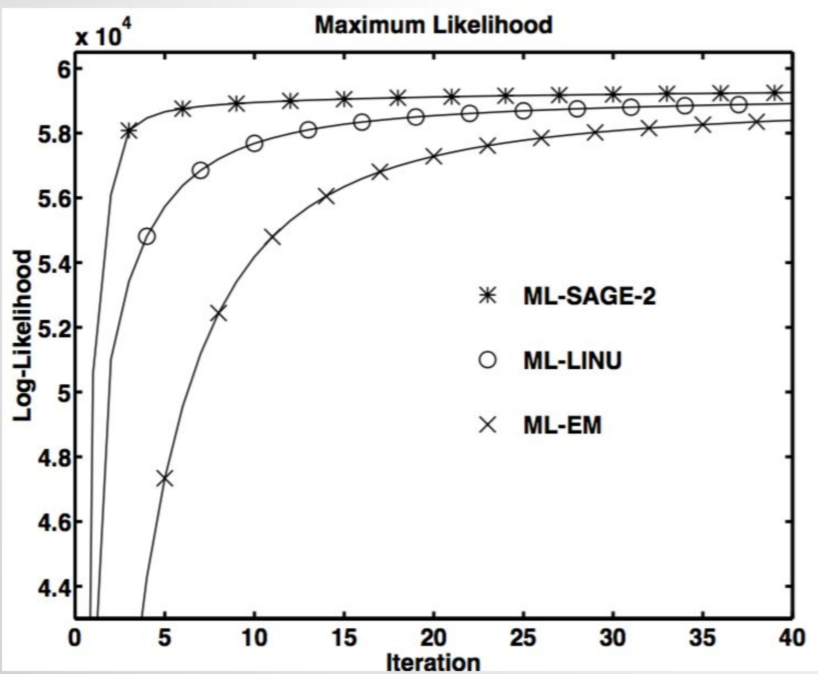


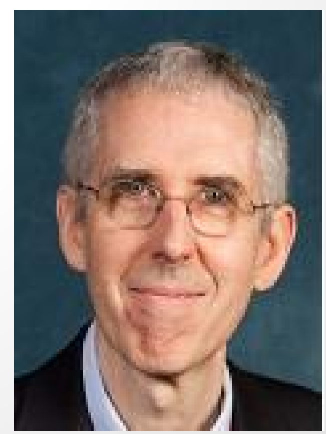
Early work with Alfred Hero

2664 IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 42, NO. 10, OCTOBER 1994

Space-Alternating Generalized Expectation-Maximization Algorithm

Jeffrey A. Fessler, *Member, IEEE,* and Alfred O. Hero, *Member, IEEE*





SPECT imaging with Ed Ficaro

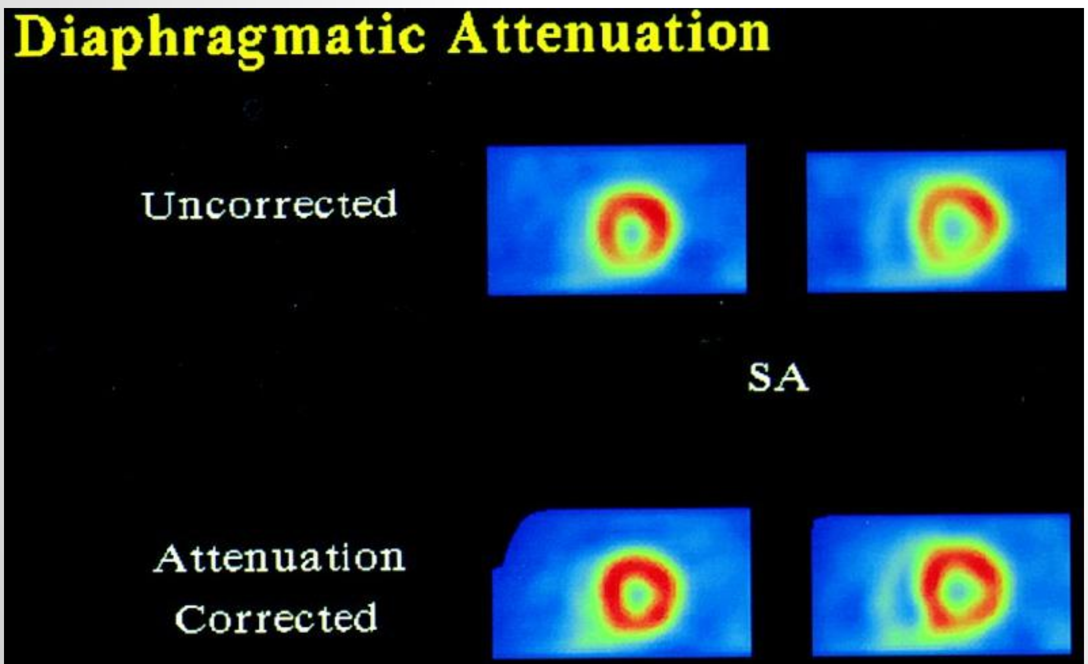
Simultaneous Transmission/Emission Myocardial Perfusion Tomography

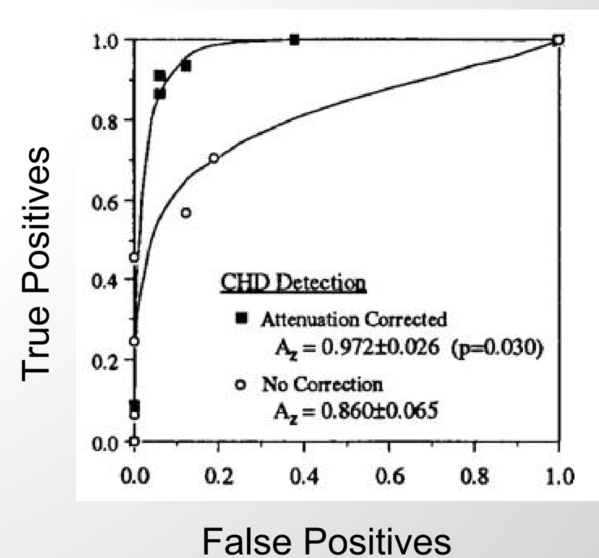
Diagnostic Accuracy of Attenuation-Corrected ^{99m}Tc-Sestamibi Single-Photon Emission Computed Tomography

Edward P. Ficaro, PhD; Jeffrey A. Fessler, PhD; Paul D. Shreve, MD;
James N. Kritzman, BS; Patricia A. Rose, BA; James R. Corbett, MD

Circulation.
1996;93:463-473
doi: 10.1161/01.CIR.93.3.463

- Abstract *Free*
- Figures Only *Free*
- » Full Text *Free*
- PPT Slides of All Figures



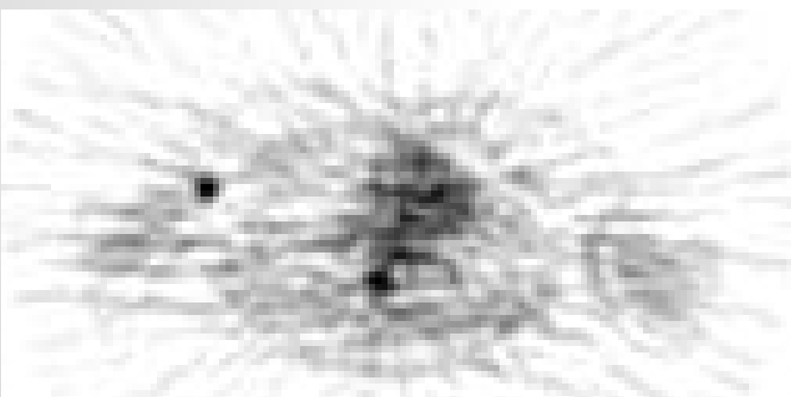


PET Reconstruction - 1994

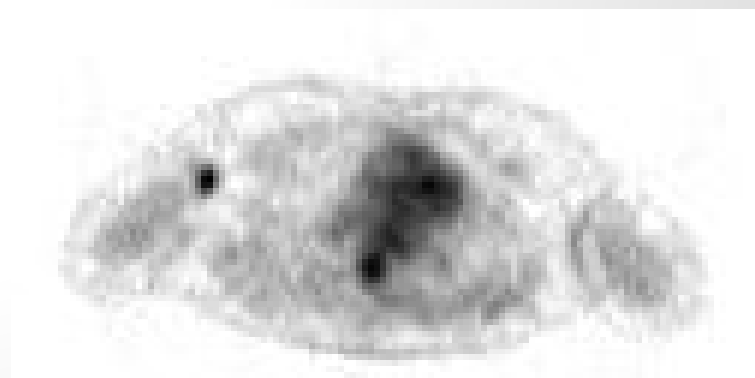
290 IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 13, NO. 2, JUNE 1994

Penalized Weighted Least-Squares Image Reconstruction for Positron Emission Tomography

Jeffrey A. Fessler



Original
(Filtered Backprojection)



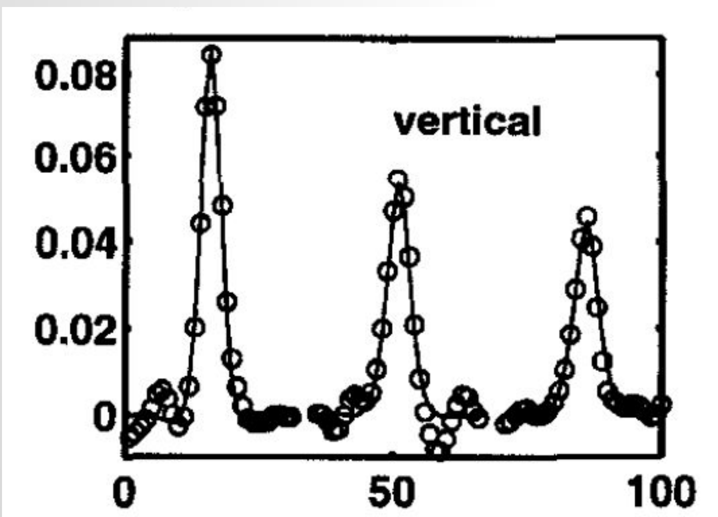
Improved
(Statistical Image Reconstruction)

Resolution and noise analyses

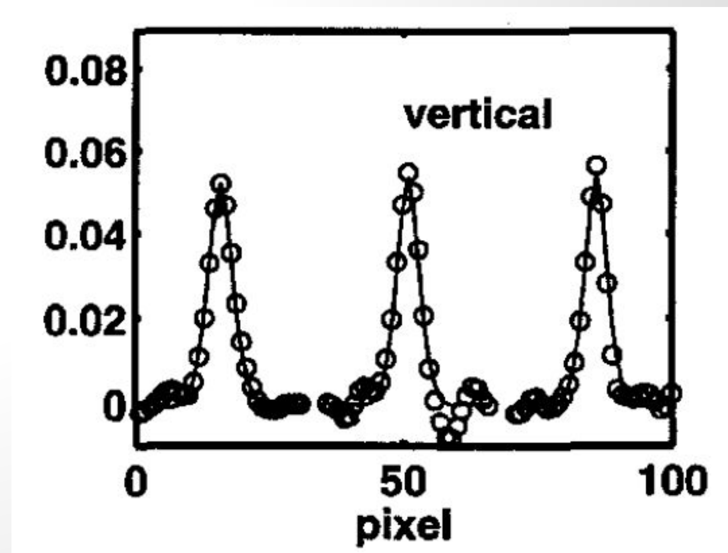
1346 IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 5, NO. 9, SEPTEMBER 1996

Spatial Resolution Properties of Penalized-Likelihood Image Reconstruction: Space-Invariant Tomographs

Jeffrey A. Fessler, *Member, IEEE*, and W. Leslie Rogers, *Member, IEEE*



Original



Modified

Resolution and noise - 20+ years

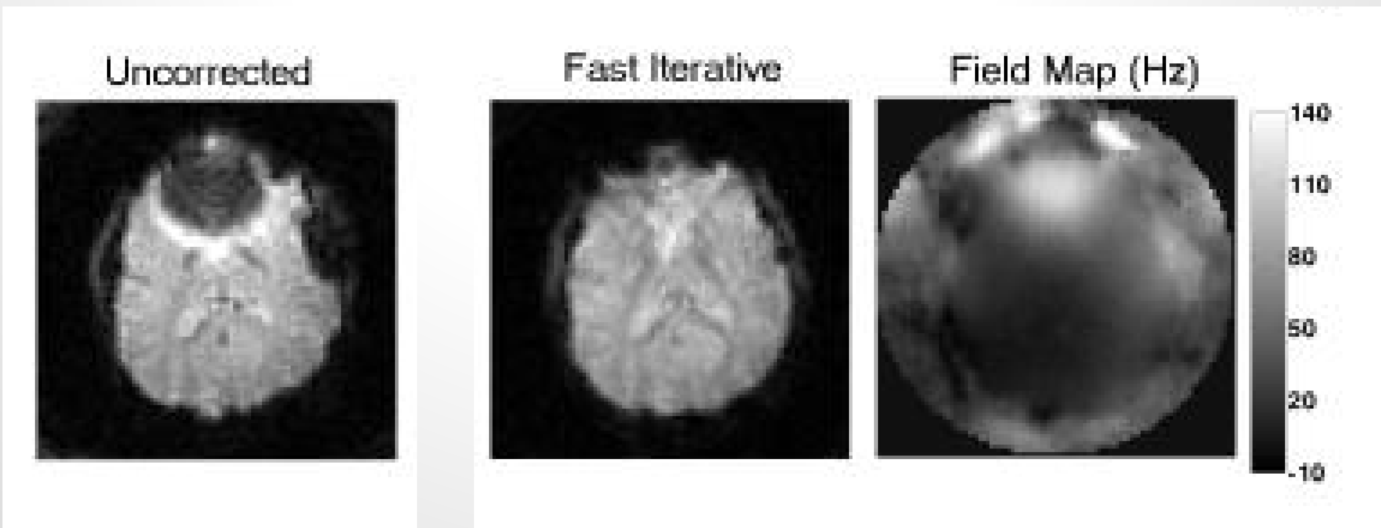
- Thanks to Rich Wahl...
- At least 8 PhD students
- Along the way, methods adopted in
  - Siemens pre-clinical PET scanners
  - GE clinical PET scanners
  - GE low-dose X-ray CT systems
- Hundreds of equations...

2001 an MRI odyssey with Doug Noll

178 IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 22, NO. 2, FEBRUARY 2003

Fast, Iterative Image Reconstruction for MRI in the Presence of Field Inhomogeneities

Bradley P. Sutton*, *Student Member, IEEE*, Douglas C. Noll, *Member, IEEE*, and Jeffrey A. Fessler, *Senior Member, IEEE*

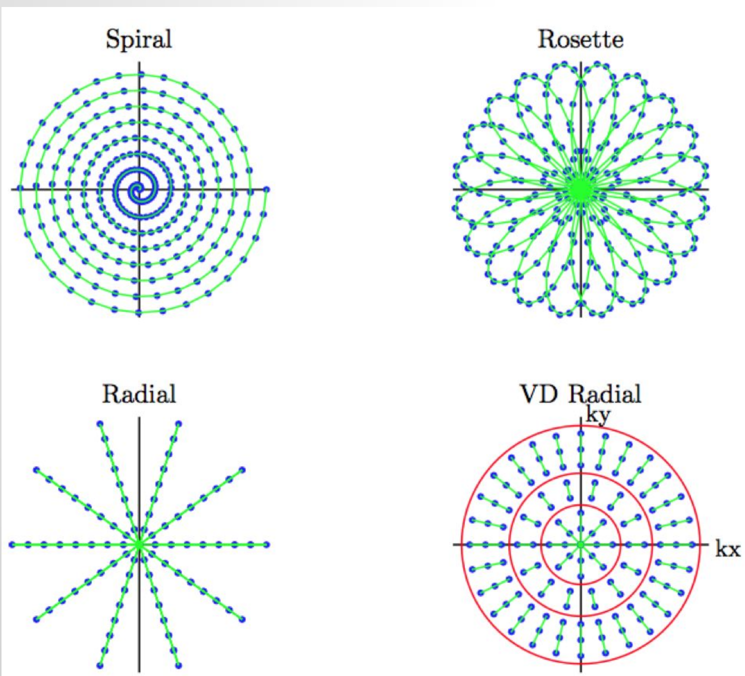


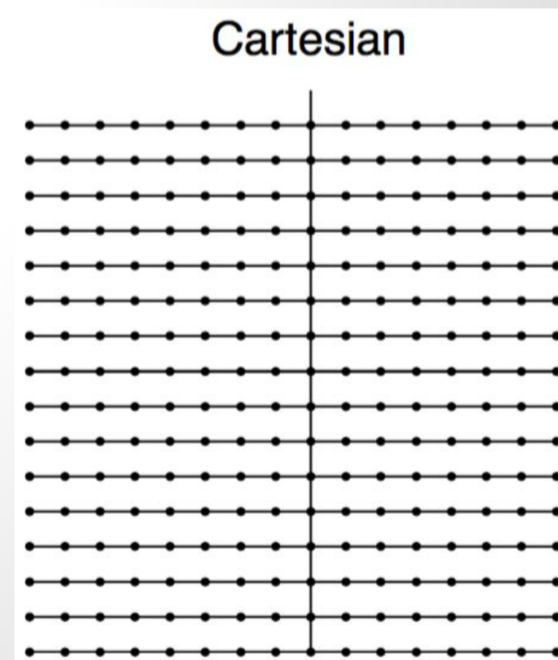
Non-Uniform FFT (NUFFT)

560 IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 51, NO. 2, FEBRUARY 2003

Nonuniform Fast Fourier Transforms Using Min-Max Interpolation

Jeffrey A. Fessler, *Senior Member, IEEE*, and Bradley P. Sutton, *Member, IEEE*





Back to 1984

1984-M radar FESSLER

Image Reconstruction from Frequency-Offset Fourier Data

DAVID C. MUNSON, JR., MEMBER, IEEE, AND JORGE L. C. SANZ, MEMBER, IEEE

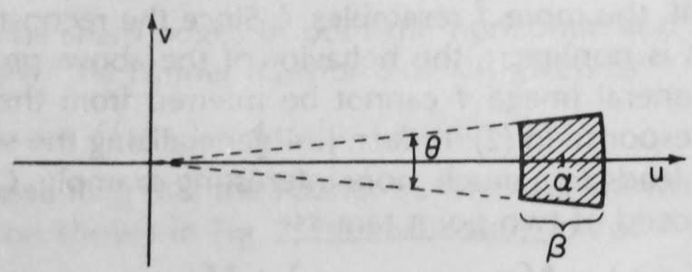


Fig. 1. Region of known Fourier-domain data $F(u, v)$ in spotlight mode synthetic-aperture radar. Typically $\beta \ll \alpha$ and θ is quite small as shown.

Manuscript received September 15, 1983; revised February 4, 1984. This research was supported by the Joint Services Electronics

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 53, NO. 1, JANUARY 2015

Novel Methods to Accelerate CS Radar Imaging by NUFFT

Shilong Sun, Guofu Zhu, *Member, IEEE*, and Tian Jin, *Member, IEEE*

Past PhD Students

Past co-advised PhD students

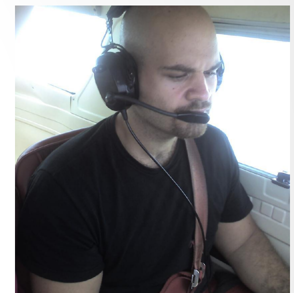
UNIVERSITY OF MICHIGAN



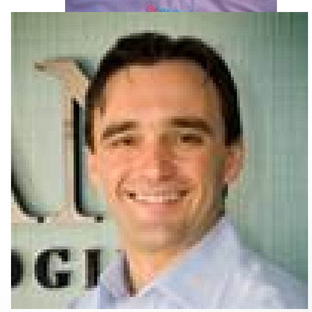








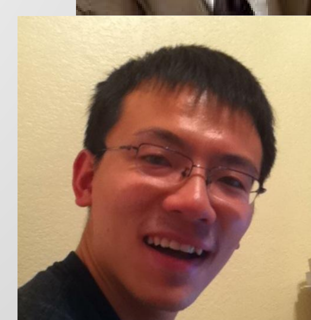


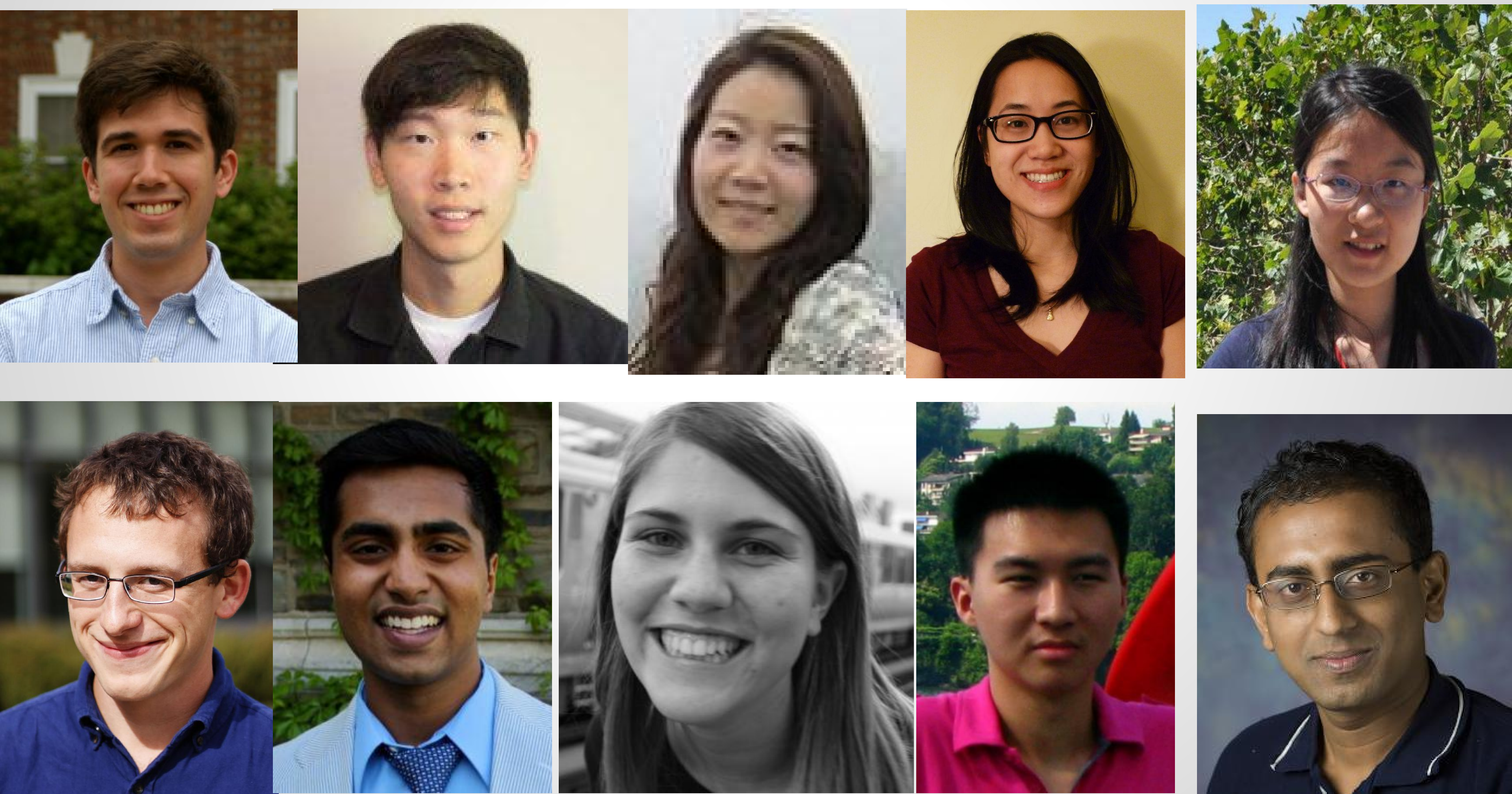








Current PhD students / postdoc



PET again: from 2003 to 2015

IOP Publishing | Institute of Physics and Engineering in Medicine — Physics in Medicine & Biology

Phys. Med. Biol. **60** (2015) 5733–5751 — doi:10.1088/0031-9155/60/15/5733

GE Healthcare

Quantitative comparison of OSEM and penalized likelihood image reconstruction using relative difference penalties for clinical PET

Sangtae Ahn[1,3], Steven G Ross[2], Evren Asma[1,4], Jun Miao[2], Xiao Jin[2], Lishui Cheng[1], Scott D Wollenweber[2] and Ravindra M Manjeshwar[1]

[1] GE Global Research, Niskayuna, NY 12309, USA

[2] GE Healthcare, Waukesha, WI 53188, USA

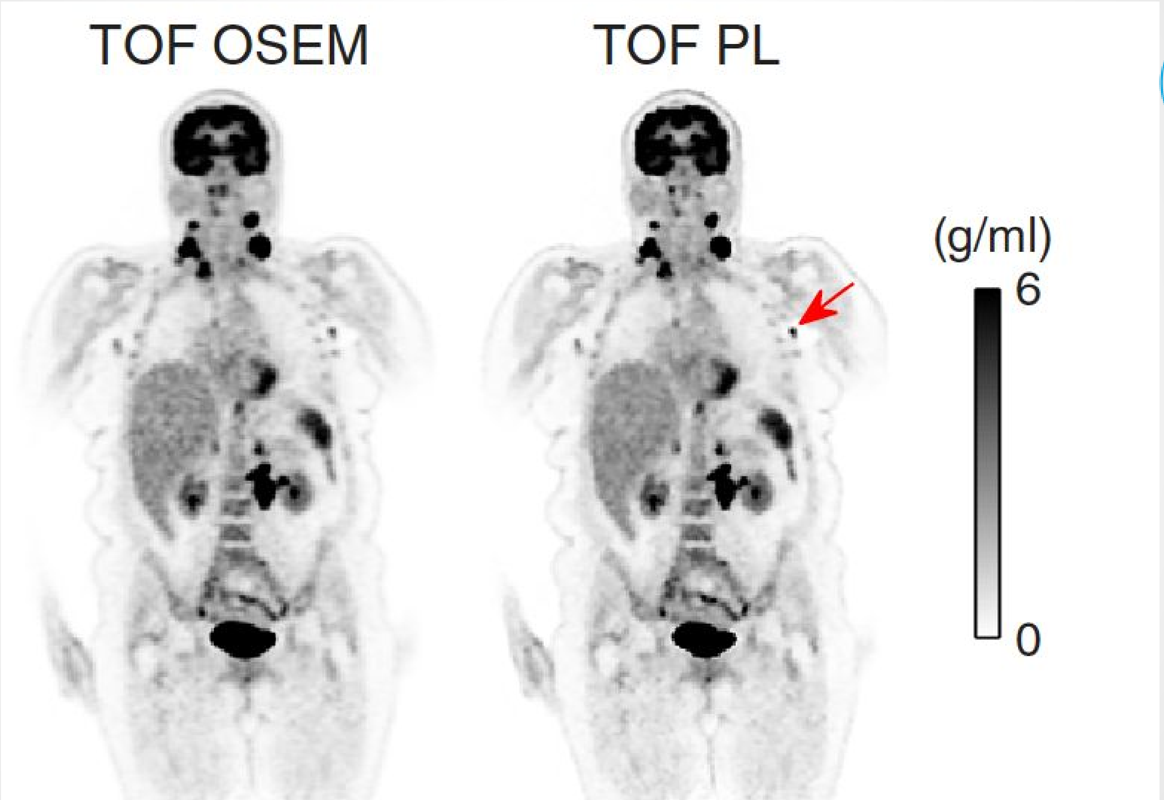
References

Ahn S, Asma E, Ross S G and Manjeshwar R M 2013 Partial volume correction for penalized-likelihood image reconstruction in oncological PET applications *Proc. IEEE Nuclear Science Symp. Medical Imaging Conf.* (doi: 10.1109/NSSMIC.2013.6829071)

Ahn S and Fessler J A 2003 Globally convergent image reconstruction for emission tomography using relaxed ordered subsets algorithms *IEEE Trans. Med. Imaging* **22** 613–26

Fessler J A and Rogers W L 1996 Spatial resolution properties of penalized-likelihood image reconstruction: space invariant tomographs *IEEE Trans. Image Process.* **5** 1346–58

PET illustration

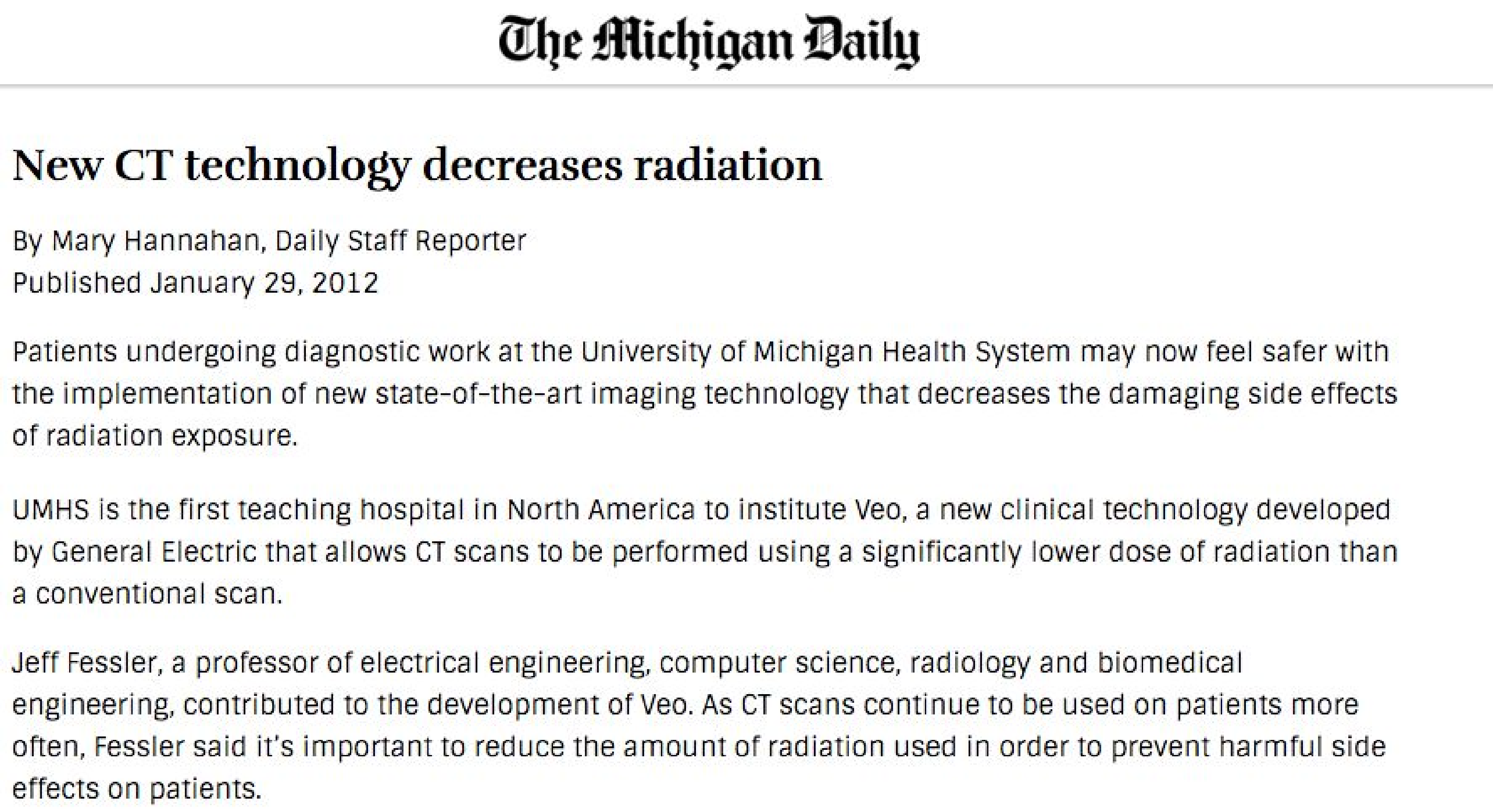


old

new

S. Ahn et al., PMB, 2015

Low-dose X-ray CT imaging



The Michigan Daily

New CT technology decreases radiation

By Mary Hannahan, Daily Staff Reporter
Published January 29, 2012

Patients undergoing diagnostic work at the University of Michigan Health System may now feel safer with the implementation of new state-of-the-art imaging technology that decreases the damaging side effects of radiation exposure.

UMHS is the first teaching hospital in North America to institute Veo, a new clinical technology developed by General Electric that allows CT scans to be performed using a significantly lower dose of radiation than a conventional scan.

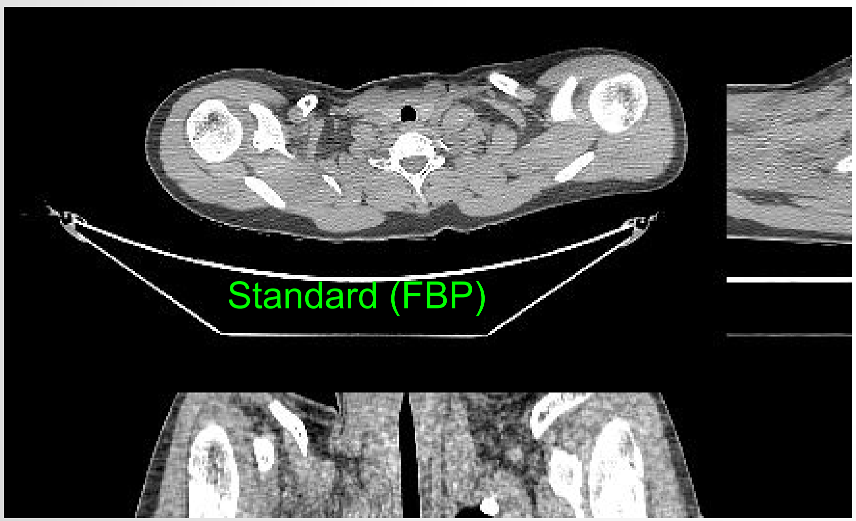
Jeff Fessler, a professor of electrical engineering, computer science, radiology and biomedical engineering, contributed to the development of Veo. As CT scans continue to be used on patients more often, Fessler said it's important to reduce the amount of radiation used in order to prevent harmful side effects on patients.

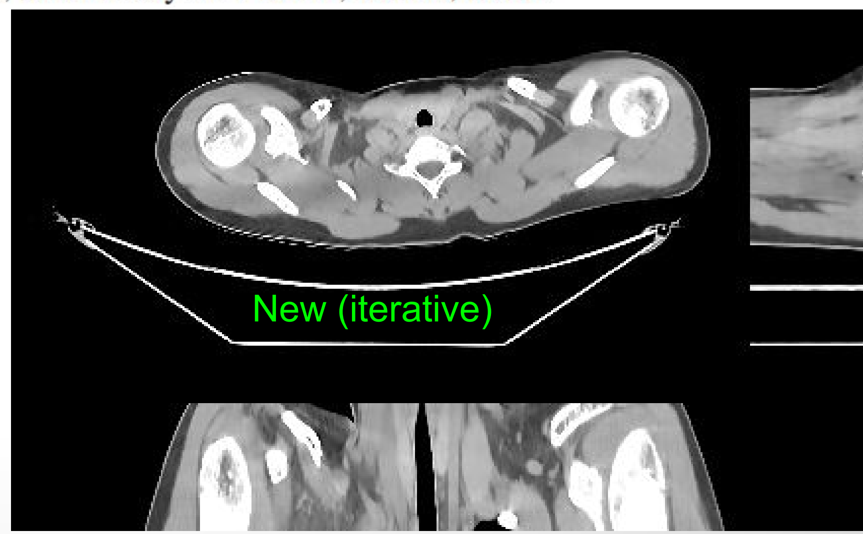
Parallelizable algorithms for CT

186 IEEE TRANSACTIONS ON COMPUTATIONAL IMAGING, VOL. 1, NO. 3, SEPTEMBER 2015

Alternating Dual Updates Algorithm for X-ray CT Reconstruction on the GPU

Madison G. McGaffin, *Member, IEEE*, and Jeffrey A. Fessler, *Fellow, IEEE*

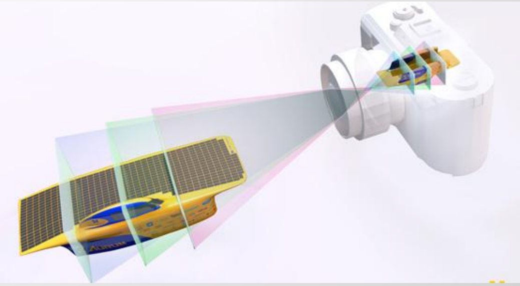




Ongoing work with Tom Wenisch, Ella Kazerooni, Heang-Ping Chan, Lubomir Hadjiiski, Mitch Goodsitt, ...

Ongoing collaborations

- Volker Sick: plenoptic imaging of chemiluminescence
- James Balter and Yue Cao: free-breathing liver MRI for radiotherapy
- Ella Kazerooni and Prachi Agarwal and Mitch Goodsitt and Tom Wenisch et al.: low-dose lung CT
- Doug Noll and Jon Nielsen: MRI RF pulse design and fast fMRI
- Jon Nielsen and Roger Albin: quantitative MRI for neuroimaging
- Yuni Dewaraja: SPECT for radionuclide therapy
- Heang-Ping Chan: digital breast tomosynthesis
- Laura Balzano: dictionary and subspace learning
- Raj Nadakuditi and Sai Ravishankar: sparse signal modeling
- Zhong He: 3D gamma imaging
- Ted Norris and Zhaohui Zhong: light-field imaging using transparent sensors
- ...



Future directions?

"Ultra-low dose CT image reconstruction based on big data priors"

UM-SJTU seed project

With Prof. Yong Long, UM-SJTU joint institute

Summary