Computational Image Formation and Enhancement

CMSE 890/BME 891
Michigan State University
MWF, 9:10-10 am EST
https://msu.zoom.us/j/98732731952
https://msu-cmse-courses.github.io/cmse890-F20-ComputationalImaging/

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Tentative Schedule

(This schedule will be updated throughout the semester)

Day 1, 09/02 (Wed): Introduction to Computational Imaging. (Discuss course goals, syllabus, software, and grading.)

Day 2, 09/04 (Fri): Basic Linear Algebra (Vectors, Matrices, Vector spaces, Inversion, singular value decomposition);
Required Reading: https://www.deeplearningbook.org/, Chapter 2.
Additional Reading: Chapters 1 and 2 of Notes on "Hilbert Spaces and Least Squares Methods for Signal Processing" by Bresler, Basu, and Couvreur.

Day ; Labor Day, 09/07 (Mon): No Class

Day 3, 09/09 (Wed): Basic Linear Algebra Continued (Vectors, Matrices, Vector spaces, Inversion, singular value decomposition)
Required Reading: https://www.deeplearningbook.org/, Chapter 2.
Additional Reading: Chapters 1 and 2 of Notes on "Hilbert Spaces and Least Squares Methods for Signal Processing" by Bresler, Basu, and Couvreur

Day 4, 09/11 (Fri): Digital Image Introduction & Active learning (Programming: Image manipulation)
Required Reading: Students will read and follow instructions provided by instructors for installing Python and Jupyter Notebooks.

Day 5, 09/14 (Mon): Signals and systems (digital, convolutions, Fourier transforms)
Required Reading: Kak and Slaney, Principles of Computerized Tomographic Imaging, Chapter 2.
Additional Reading: Richard Blahut, Theory of Remote Image Formation, Chapters 2 and 3.
Chapter 2 of Principles of Magnetic Resonance Imaging: A Signal Processing Perspective (Zhi-Pei Liang and Paul C. Lauterbur).
Doug Noll's FT notes: https://web.eecs.umich.edu/∼dnoll/BME516/

Day 6, 09/16 (Wed): Signals and systems cont'd (FT, DFT, 2-DFT, w/example)
Required Reading: Kak and Slaney, Principles of Computerized Tomographic Imaging, Chapter 2.
Additional Reading: Richard Blahut, Theory of Remote Image Formation, Chapters 2 and 3.
Chapter 2 of Principles of Magnetic Resonance Imaging: A Signal Processing Perspective (Zhi-Pei Liang and Paul C. Lauterbur).
Doug Noll's FT notes: https://web.eecs.umich.edu/∼dnoll/BME516/

Day 7, 09/18 (Fri): Image Quality & Active learning (Programming: FFTs)
Required Reading: Students will look through assignment before class and discuss and work on it during class.

Day 8, 09/21 (Mon): Introduction to optical image collection
Required Reading: Pages 1-8 of Doug Noll's notes on nuclear medicine and cameras.
Additional Reading: Jürgen Beyerer and Fernando Puente León and Christian Frese, *Machine Vision: Automated Visual Inspection: Theory, Practice and Applications*, Chapter 7.
Junichi Nakamura, Image Sensors and Signal Processing for Digital Still Cameras, CRC Press, 2006.

Day 9, 09/23 (Wed): Imaging with Ionizing Radiation
Required Reading: J. M. Ollinger and J. Fessler, "Positron-emission tomography," IEEE Signal Processing, 1997.
Doug Noll's notes on emission computed tomography.
Additional Reading: Kak and Slaney, Chapter 4.

Day 10, 09/25 (Fri): PET, SPECT – physics and image formation
Required Reading: J. M. Ollinger and J. Fessler, "Positron-emission tomography," IEEE Signal Processing, 1997.
Additional Reading: Kak and Slaney, Chapter 4.

Day 11, 09/28 (Mon): Active Learning (Programming: build tomographic forward projector)
Required Reading: Students will look through assignment before class and discuss and work on it during class.

Day 12, 09/30 (Wed): Continuation of PET and SPECT Physics
Additional Reading: Bushberg et al, Essential Physics of Medical Imaging, Chapter 18 & 19

Day 13, 10/02 (Fri): CT 1 (physics of imaging process)
Required Reading: Doug Noll's online notes on CT Physics and reconstruction. xr_notes1.pdf and xr_notes2.pdf.
Additional Reading: Bushberg et al, Essential Physics of Medical Imaging, Chapter 10
Additional Reading: Jeff Fessler's: Physics of projection radiography
Additional Reading: Kak and Slaney, Chapter 4.

Day 14, 10/05 (Mon): CT 2 (image formation, Fourier slice theorem, basic tomographic recon)
Required Reading: Kak and Slaney, Chapter 3; Sections 3.1-3.3.
Additional Reading: Jeff Fessler's: Analytical Tomographic Image Reconstruction Methods

Day 15, 10/07 (Wed): Active Learning (Programming: Inverse Radon Transform through Filtered Backprojection (FBP))
Required Reading: Students will look through assignment before class and discuss and work on it during class.

Day 16, 10/09 (Fri): MRI 1 (physics)
Required Reading: Wright, Magnetic Resonance Imaging, IEEE Signal Processing, 1997.
Required Reading: Zhi-Pei Liang and Paul C. Lauterbur, Principles of Magnetic Resonance Imaging: A Signal Processing Perspective – Chapter 3.
Additional Reading: Bushberg et al, Essential Physics of Medical Imaging, Chapter 12&13
Additional Reading: Jeff Fessler's and Doug Noll's notes on MRI.

Day 17, 10/12 (Mon): MRI 2 (physics and signal detection)
Required Reading: Wright, Magnetic Resonance Imaging, IEEE Signal Processing, 1997.
Required Reading: Zhi-Pei Liang and Paul C. Lauterbur, Principles of Magnetic Resonance Imaging: A Signal Processing Perspective – Chapter 3.
Additional Reading: Bushberg et al, Essential Physics of Medical Imaging, Chapter 12&13
Additional Reading: Jeff Fessler's and Doug Noll's notes on MRI.

Day 18, 10/14 (Wed): MRI 3 (the MRI signal, spin echoes, gradient echoes)
Required Reading: Zhi-Pei Liang and Paul C. Lauterbur, Principles of Magnetic Resonance Imaging: A Signal Processing Perspective – Chapters 3 and 4.
Additional Reading: Jeff Fessler's and Doug Noll's notes on MRI.

Day 19, 10/16 (Fri): MRI 4 (image formation – slice selection, frequency and phase encoding, k-space, sampling and reconstruction: trajectories for 2D/3D, non-Cartesian, etc.)
Required Reading: Zhi-Pei Liang and Paul C. Lauterbur, Principles of Magnetic Resonance Imaging: A Signal Processing Perspective – Chapters 5 and 6.
Homework 2 Released (PET,CT, and MRI Topics)

Day 20, 10/19 (Mon): Active Learning (Programming: Simulate+Reconstruct MR data)

Day 21, 10/21 (Wed): Introduction to noise and image enhancement
Required Reading: Jürgen Beyerer and Fernando Puente León and Christian Frese, Machine Vision: Automated Visual Inspection: Theory, Practice and Applications, *Chapter 9.*
Additional Reading: K. Dabov, A. Foi, V. Katkovnik and K. Egiazarian, "Image Denoising by Sparse 3-D Transform-Domain Collaborative Filtering," in IEEE Transactions on Image Processing, vol. 16, no. 8, pp. 2080-2095, Aug. 2007.
A. Buades, B. Coll and J. -M. Morel, "A non-local algorithm for image denoising," 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05), San Diego, CA, USA, 2005, pp. 60-65 vol. 2.
M. Elad, Sparse and Redundant Representations: From Theory to Applications in Signal and Image Processing, Springer-Verlag New York, 2010. (Chapter 14)

Day 22, 10/23 (Fri): Active Learning (Programming: Basic denoising and edge enhancement methods)

Day 23, 10/26 (Mon): Introduction to model-based image reconstruction (Objective functions, models for your data/image, WLS, PWLS, Introduce idea of needing optimization algorithms)
Required Reading: Doug Noll's notes on model-based image reconstruction.
J. A. Fessler, "Model-Based Image Reconstruction for MRI," in IEEE Signal Processing Magazine, vol. 27, no. 4, pp. 81-89, July 2010.
B. D. Man and J. A. Fessler, "Statistical iterative reconstruction for X-ray computed tomography," in Biomedical Mathematics: Promising Directions in Imaging, Therapy Planning and Inverse Problems (Y. Censor, M. Jiang, and G. Wang, eds.), pp. 113–40, Medical Physics Publishing, Madison, 2010.

Day 24, 10/28 (Wed): Complete model-based image reconstruction lecture and begin review of optimization for convex or nonconvex problems.
Required Reading: Doug Noll's notes on model-based image reconstruction.
Required Reading: S. Boyd and L. Vandenberghe, Convex Optimization. Cambridge University Press, 2004.

Day 25, 10/30 (Fri): Optimization algorithms for convex or nonconvex problems: gradient-based methods, proximal gradient methods, ADMM, block coordinate descent, etc.
Required Reading: S. Boyd and L. Vandenberghe, Convex Optimization. Cambridge University Press, 2004 – Chapter 9.
S. Boyd, N. Parikh, E. Chu, B. Peleato, and J. Eckstein, "Distributed optimization and statistical learning via the alternating direction method of multipliers," Foundations and Trends in Machine Learning, vol. 3, no. 1, pp. 1–122, Jan. 2011. (Chapter 3)
Additional Reading: A. Chambolle and T. Pock, An introduction to continuous optimization for imaging, Acta Numerica, vol. 25, pp. 161-319, 2016.

Day 26, 11/02 (Mon): Complete optimization review and begin lecture on sparsity and compressed sensing - principles and algorithms
Required Reading: S. Boyd and L. Vandenberghe, Convex Optimization. Cambridge University Press, 2004 – Chapter 9.
S. Boyd, N. Parikh, E. Chu, B. Peleato, and J. Eckstein, "Distributed optimization and statistical learning via the alternating direction method of multipliers," Foundations and Trends in Machine Learning, vol. 3, no. 1, pp. 1–122, Jan. 2011. (Chapter 3)
Required Reading: M. Elad, Sparse and Redundant Representations: From Theory to Applications in Signal and Image Processing, Springer-Verlag New York, 2010. (Chapters 1 and 3)
A. M. Bruckstein, and D. L. Donoho, and M. Elad, "From sparse solutions of systems of equations to sparse modeling of signals and images," SIAM Review, vol. 51, no. 1, pp. 34-81, 2009.
Additional Reading: J. A. Tropp and S. J. Wright, "Computational Methods for Sparse Solution of Linear Inverse Problems," in Proceedings of the IEEE, vol. 98, no. 6, pp. 948-958, June 2010.
Y. C. Eldar and G. Kutyniok, Compressed Sensing : Theory and Applications, Cambridge University Press, 2012. (Chapter 1)

Day 27, 11/04 (Wed): Midterm Exam

Day 28, 11/06 (Fri): Invited Guest: Dr. Bruno De Man, GE Global Research, "Active Projects in CT Image Generation: MBIR to Deep Learning"

Day 29, 11/09 (Mon): Students Summarize Paper: Fu et al., "Comparison Between Pre-Log and Post-Log Statistical Models in Ultra-Low-Dose CT Reconstruction," IEEE Trans Medical Imaging, 36:3, 2017, doi: 10.1109/TMI.2016.2627004.

Day 30, 11/11 (Wed): Students Summarize Paper: Lustig et al., "Sparse MRI: The application of compressed sensing for rapid MR imaging," Magn. Reson. Med., 58, 2007. doi:10.1002/mrm.21391.

Day 31, 11/13 (Fri): Complete Paper Presentations; Compressed Sensing
Homework 3 Released (model-based image reconstruction/optimization/compressed sensing topics)

Day 32, 11/16 (Mon): Complete lecture on compressed sensing algorithms - orthogonal matching pursuit and ℓ_1 optimization
Required Reading: M. Elad, Sparse and Redundant Representations: From Theory to Applications in Signal and Image Processing, Springer-Verlag New York, 2010. (Chapters 1 and 3)
A. M. Bruckstein, and D. L. Donoho, and M. Elad, "From sparse solutions of systems of equations to sparse modeling of signals and images," SIAM Review, vol. 51, no. 1, pp. 34-81, 2009.

Day 33, 11/18 (Wed): Active Learning (Programming: implement algorithms for compressed sensing)

Day 34, 11/20 (Fri): Introduction to machine learning and dictionary learning/transform learning
Required Reading: https://www.deeplearningbook.org/, Chapter 5: Machine Learning Basics.
M. Elad, Sparse and Redundant Representations: From Theory to Applications in Signal and Image Processing, Springer-Verlag New York, 2010. (Chapters 12 and 14)
Additional Reading: A. M. Bruckstein, and D. L. Donoho, and M. Elad, "From sparse solutions of systems of equations to sparse modeling of signals and images," SIAM Review, vol. 51, no. 1, pp. 34-81, 2009.
Additional Reading: B. Wen, S. Ravishankar, L. Pfister and Y. Bresler, "Transform Learning for Magnetic Resonance Image Reconstruction: From Model-Based Learning to Building Neural Networks," in IEEE Signal Processing Magazine, vol. 37, no. 1, pp. 41-53, Jan. 2020.

Day 35, 11/23 (Mon): Deep learning for imaging - introduction
Required Reading: M. T. McCann and M. Unser, "Biomedical Image Reconstruction: From the Foundations to Deep Neural Networks", Foundations and Trends in Signal Processing: Vol. 13: No. 3, pp 283-359, 2019.
Additional Reading: S. Ravishankar, J. C. Ye and J. A. Fessler, "Image Reconstruction: From Sparsity to Data-Adaptive Methods and Machine Learning," in Proceedings of the IEEE, vol. 108, no. 1, pp. 86-109, Jan. 2020.
https://www.deeplearningbook.org/, Chapters 6 and 9.

Day 36, 11/25 (Wed): Active Learning (Programming assignment on deep learning for imaging). Invited guest lecturer: Dr. Michael McCann, Postdoc, CMSE.

Day Thanksgiving Holiday, 11/27 (Fri): No Class

Day 37, 11/30 (Mon): Invited Guest: Dr. Desmond Yeo, GE Global Research, "MRI Advances".

Day 38, 12/02 (Wed): Course Review and wrap-up Day.

Day 39, 12/04 (Fri): Project Presentations: Learn from each other and ask questions!

Day 40, 12/07 (Mon): Project Presentations

Day 41, 12/09 (Wed): Project Presentations

Day 42, 12/11 (Fri): Project Presentations: **Last Day of Class**