BIM252/EEC205 Computational Methods in Biomedical Imaging

University of California, Davis
Department of Biomedical Engineering

Overview: In this course, we will concentrate on tomographic reconstruction algorithms, their mathematical foundations, and their properties. We will cover both analytic and model-based approaches. The analytic methods are based on Fourier and Radon transform relationships between the image and data, and their properties are based primarily on linear system theory. The model-based approaches typically draw on stochastic process models, linear algebra and numerical optimization methods to develop algorithms for image estimation. On completing this course, you will be familiar with the methods that are used to form images in most of the biomedical imaging modalities including x-ray CT, PET, and SPECT. Some methods also have applications in MRI, diffuse optical tomography, and ultrasound imaging.

Prerequisite: An appropriate background for this course includes calculus, linear algebra, probability, Fourier transform, and linear system theory. Knowledge of the physics of imaging systems and random processes will also be helpful. While the basic background material will be assumed, we will review certain key concepts during the course before applying them to the specific reconstruction problems that will be addressed. You also need to know programming in MATLAB.

Schedule: Lectures: TR 10am -11:50am, HUTCH 102

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Reference books
The first two are highly recommended:

1. G L Zeng, *Medical Image Reconstruction A Conceptual Tutorial*, Spinger, ISBN 978-3-642-05368-9. Book PDF can be downloaded from SpringerLink https://link.springer.com/book/10.1007%2F978-3-642-05368-9
2. A.C. Kak, M. Slaney, *Principles of Computerized Tomographic Imaging* (Classics in Applied Mathematics, 33), 089871494X, Society for Industrial & Applied Mathematics; July 2001. (this is a well cited book, now available for download in PDF from http://www.slaney.org/pct/pct-toc.html)
3. Jeffrey A. Fessler, *Image Reconstruction: Algorithms and Analysis*. A pre-publication copy of this book is available for download at http://web.eecs.umich.edu/~fessler/book/
4. C. Epstein, *Mathematics of Medical Imaging*, Prentice Hall. ISBN: 0130675482; 1st edition, FEB, 2003.
5. F. Natterer and F. Wubbeling (eds), *Mathematical Methods in Image Reconstruction*, ISBN: 0898714729, Society for Industrial & Applied Mathematics; 1st edition, December 15, 2001
6. F. Natterer, *The Mathematics of Computerized Tomography* (Classics in Applied Mathematics, 32)", ISBN: 0898714931, Society for Industrial & Applied Mathematics; July 2001.

Class Attendance: Class attendance is highly recommended, because materials outside the text will be covered.

Grading

Your grade will be based on three components:

20% - Homework (will include both analytic problems and MATLAB problems. Computing accounts on engineering PCs located in 1116 Academic Surge are available to all registered students upon request.)

30% - Exam 1 (covers part 1 Analytic methods and will be closed book. Date: **Feb 12**)

30% - Exam 2 (covers part 2 Model based methods and closed book. Date: **March 14**)

20% - Project (Details will be given in Week 6)

Academic Integrity:

Cheating and plagiarism will not be tolerated. Professional integrity is an important aspect of all engineering disciplines and understanding the material in these courses is integral to becoming a proficient and productive engineer. As such, it is imperative that you spend the time and effort to fully understand the material. Students who violate the Code of Academic Conduct are subject to disciplinary sanctions that include censure, probation, suspension, deferred separation or dismissal from the University of California. A few examples of misconduct are

- Posting or sharing any course materials of an instructor without the explicit written permission of that instructor.
- Purchasing or copying assignments or solutions, to complete any portion of graded work, without the instructor's permission.
- Unauthorized use of another student's work.

Please read the UC Davis “Code of Academic Conduct” at https://ossja.ucdavis.edu/code-academic-conduct.

Course Outline

Part 1: Analytic Reconstruction Methods.

1. Introduction. Review of Fourier transform, delta functions and convolutions. Polar vs. Cartesian coordinates.
   The Radon transform; the Fourier-slice theorem; Direct Fourier reconstruction; backprojection filtering.
2. Filtered backprojection and Practical implementation considerations.
3. Fan beam reconstruction and helical scan.
4. Radon transform in higher dimensions.
5. Introduction to cone beam reconstruction: Feldkamp’s algorithm, Tuy’s condition and Grangeat’s formula.
6. 3D parallel-beam tomography: the x-ray transform; Orlov’s condition, filtered backprojection in 3D; Colsher filters; 3D reprojection methods.
7. Fully 3D PET and Fourier rebinning: Exact and approximate Fourier rebinning methods for 3D reconstruction; frequency-distance relation. (time permits)

Part 2: Model Based Reconstruction Methods

1. Problem formulation: finite dimensional formulations and choice of basis function; system models; forward and back projection operators; algebraic reconstruction methods (ART)
2. Statistical reconstruction approaches: Least squares, maximum likelihood and MAP formulations. Properties of estimators; Gaussian and Poisson noise models; penalty functions and priors.
3. General numerical optimization principles: convexity, local and global minima; the Hessian matrix; Kuhn-Tucker conditions; constrained optimization.
4. Optimization using surrogate functions and the EM algorithm for Poisson likelihood functions
5. Other optimization methods: steepest descent; Newton Raphson; conjugate gradient methods; iterated coordinate ascent.
6. Sparsity and non-smooth optimization
7. Deep learning based image reconstruction (time permits)