BMSC-GA 4428 - Practical Magnetic Resonance Imaging II
6 credits

Course director: Ricardo Otazo, PhD

Course description:

This course is a practical introduction to image reconstruction, image analysis and statistical analysis in magnetic resonance imaging (MRI). The course is divided in three modules:
1. Image reconstruction: Fourier imaging, partial Fourier, parallel imaging and compressed sensing, with in-depth mathematical descriptions of the most common algorithms.
2. Image representation and analysis: tissue/organ segmentation, coregistration and kinetic modeling of dynamic MRI.
3. Biostatistical analysis: power and sample size, P-value, ANOVA.

During laboratory sessions and homework assignments, students will use Matlab and FireVoxel to implement and test the different methods discussed in class. Prerequisites are G16.4427 or permission of the course director for students not enrolled in the Sackler training program in biomedical imaging.

Goals and Objectives:

- Teach students basic and advanced methods for MR image reconstruction
- Present clinically relevant concepts of medical image processing
- Provide an introduction of core applied statistical concepts and methods
- Review the mathematics behind the most common techniques and expose students to practical examples.

Format:
The course meets twice per week and it is organized as fourteen 120-minute lectures, ten 180-minute labs and two exams. Students will be evaluated based on two exams (40%), homework assignments (30%) and laboratory projects (30%).
Part 1 – Image reconstruction (Ricardo Otazo, PhD)

Lecture #1 k-space sampling and Fourier reconstruction (9/6/16)
• Introduction to the course
• Spatial encoding and k-space
• Sampling theorem and aliasing
• Fourier image reconstruction
• Point spread function and image resolution
• Zero-padding and windowing

Laboratory #1 Fourier image reconstruction (9/9/16)
• Review of Matlab commands
• Generate k-space representation of an image and recover original image
• Effects of undersampling, zero-padding and windowing

Lecture #2 Partial Fourier imaging (9/13/16)
• Conjugate symmetry
• Margosian and homodyne reconstruction
• Iterative partial Fourier reconstruction

Laboratory #3 Partial Fourier reconstruction (9/16/16)
• Margosian reconstruction
• POCS algorithm

Lecture #3 Non-Cartesian sampling and reconstruction (9/20/16)
• Radial and spiral sampling trajectories
• Regridding and density compensation
• Backprojection reconstruction

Laboratory #3 Reconstruction of non-Cartesian k-space data (9/23/16)
• Regridding reconstruction of radial and spiral k-space data
• Non-uniform FFT

Lecture #4 Parallel imaging in the spatial domain: SENSE (9/27/16)
• Multicoil systems and coil sensitivity encoding
• SENSE parallel imaging reconstruction
• g-factor

Laboratory #4 SENSE image reconstruction (9/30/16)
• Estimation of coil sensitivities
• SENSE reconstruction of an undersampled brain image

Lecture #5 Parallel imaging in k-space: SMASH and GRAPPA (10/4/16)
• SMASH parallel imaging reconstruction
• GRAPPA parallel imaging reconstruction
Laboratory #5 GRAPPA image reconstruction (10/7/16)
• GRAPPA kernel estimation
• GRAPPA reconstruction of a undersampled brain image

Lecture #6 Compressed sensing MRI (10/11/16)
• Compressed sensing theory
• MRI compressibility and sparsifying transforms
• Incoherent k-space sampling
• Non-linear reconstruction: iterative soft-thresholding
• Combination of compressed sensing and parallel imaging

Laboratory #6 Compressed sensing reconstruction (10/18/16)
• Random k-space undersampling of MRI data
• Reconstruction using iterative soft-thresholding

Lecture #7 Dynamic imaging (10/21/16)
• Spatiotemporal correlations and sparsity
• Temporal parallel imaging: TSENSE and TGRAPPA
• k-t SENSE and k-t GRAPPA
• Compressed sensing for dynamic imaging

Lecture #8 Model-based reconstruction (10/25/16)
• MR signal models: B0 inhomogeneity, T1 and T2 relaxation
• Iterative model-based reconstruction algorithms

Exam 1 (20%): 10/28/16

Part 2 – Medical image analysis (Henry Rusinek, PhD)

Lecture #9 Image representation and basic image processing techniques. (11/1/16)
• File formats: DICOM, Analyze
• Look-up tables, organizing slices into volumes, regions of interest
• Spatial filtering, convolution and transformations
• Non-uniformity correction: homeomorphic filtering, histogram-based methods

Laboratory #7 Basic image processing operations. (11/3/16)
• Spatial filtering and convolutions
• Spatial transformation (translations/rotations/affine)
• ROIs and morphological manipulations
• Image histogram, computations of histogram features

Lecture #10 Image segmentation (11/8/16)
• The role of segmentation in medical imaging
• Manual ROI editing
• Thresholding
- Erosion and dilation operators
- Region growing

**Lecture #11 Noise in MR images (11/11/15)**
- Parameters affecting image noise and SNR
- Basic concepts of probability distributions: expectation & variance
- Gaussian and Rayleigh distributions, simulating pseudorandom noise in Real, Imaginary & Magnitude images
- Rician Distribution
- Implication for parametric mapping (T2-mapping, ADC)
- Denoising filters
- Physiologic vs. thermal noise
- Noise in parallel imaging

**Laboratory #8 Segmentation at work: EdgeWave (11/15/16)**
- FireVoxel segmentation tools
- Improving segmentation by filtering and uniformity correction
- White matter lesion load: multi-stage segmentation
- Validation of segmentation methods: Hausdorff distance and Dice coefficients

**Lecture #12 Parametric mapping and dynamic models (11/18/16)**
- Estimating T1, T2 and ADC
- Non-linear fitting for IVIM models
- DCE-MRI models with arterial input for tumor perfusion

**Lecture #13 Image coregistration (11/22/16)**
- Classification of registration problems
- Landmark methods
- Cost functions
- Optimization strategies
- Mutual Information
- Validation of coregistration methods

**Laboratory #9 Coregistration at work (11/29/16)**
- Landmark matching
- Correlational approach
- Mutual Information applied to dynamic imaging

**Part 3 – Biostatistics (James Babb, PhD)**

**Lecture #14 Statistics (12/2/16)**
- Accuracy versus precision
- The Gaussian probability distribution
- Type I and Type II errors
• Rayleigh distribution
• Rician distribution

Lecture #15 Statistical analysis (12/6/16)
• P-value
• Power and sample size in study design
• Analysis of variance (ANOVA) and t-test
• Regression and correlation
• Non-parametric statistical methods

Laboratory #10 Statistical exercises (12/9/16)
• Interpret differences in data distributions via visual display
• Calculate standard scores and resulting probabilities
• Calculate and interpret confidence intervals for population means
• Perform a two-sample t-test and interpret the results
• Perform an ANOVA and interpret the results

Exam 2 (20%): 12/13/16