Workshop on Diffusion Tensor Imaging and Brain Connectivity

Building 001 Room 308,
Seoul National University Hospital, Korea

December 2-3 2011 1:00-6:00pm

Session 1: Diffusion Tensor Imaging December 2 1:00-6:00pm

Andrew Alexander, University of Wisconsin-Madison
Diffusion Tensor Imaging, Tractography and Beyond

Ameer Hosseinbor, University of Wisconsin-Madison
Bessel Fourier Orientation Reconstruction: An Analytic EAP Reconstruction Using Multiple Shell Acquisition in Diffusion MRI

Anqi Qiu, National University of Singapore
Diffeomorphic HARDI Registration and Atlas Generation

Nagesh Adluru, University of Wisconsin-Madison,
Large Scale Data Mining of DTI in Non-Human Primates

Seung-Goo Kim, Seoul National University
White Matter Structural Connectivity Without Diffusion Tensor Imaging

Session 2: Brain Connectivity December 3 1:00-4:00pm

Hae-Jeong Park, Yonsei University, Korea
Intrinsic Brain Connectivity Using fMRI and DTI

June Sic Kim, Seoul National University Hospital, Korea
Clinical Applications of Brain Connectivity Using Electrophysiological Data

Hyekyoung Lee, Seoul National University
Decomposition of Weighted Networks Using Network Filtration and Persistent Homology

Session 3: Machine Learning December 3 4:00-6:00pm

Vikas Singh, University of Wisconsin-Madison
Kernel Learning for Graph Partitioning Objectives: Applications to Multi-Modality Inference Problems In NeuroImaging

Moo K. Chung, University of Wisconsin-Madison, SNU
Overview and Discussion

Please contact Moo K. Chung
email: mkchung@wisc.edu
for additional information.

Session 1. Diffusion Tensor Imaging
December 2, 1:00-4:00pm

Andrew L. Alexander, Ph.D.
Department of Medical Physics,
Waisman Laboratory for Brain Imaging and Behavior,
University of Wisconsin-Madison

Diffusion Tensor Imaging, Tractography and Beyond

Abstract: Diffusion tensor imaging (DTI) is an extremely sensitive imaging method for detecting and characterizing differences in brain tissue microstructure and organization as a function of pathology, development and aging, and white matter plasticity. It may also be used to estimate the trajectories of white matter pathways in the brain. One of the major limitations of DTI is that it does not accurately describe the microstructure in cases of partial volume averaging of different tissues – crossing white matter fibers in particular. More advanced diffusion imaging methods like high angular resolution diffusion imaging (HARDI) and diffusion spectrum imaging (DSI) have been developed in recent years to more completely describe the microstructural properties and orientations of multiple fiber groups. In this presentation, I will review the methods and issues associated with DTI (tensor estimation and measures), strategies for image analysis (spatial normalization and templates), tractography approaches (deterministic, probabilistic, global), and methods for characterizing complex diffusion and white matter organization. I will try to describe what I think are the important and unanswered questions and need for tools in this exciting area of neuroimaging.

Bio: Andrew L. Alexander, Ph.D., is Associate Professor of Medical Physics and Psychiatry, and Director of MR Physics Research at the Waisman Laboratory for Brain Imaging and Behavior, all at the University of Wisconsin – Madison. Professor Alexander is an expert in medical physics and his research is focused on methods for quantitative neuroimaging with MRI. His research is focused on all aspects of quantitative MRI including the acquisition, application, processing, analysis, and interpretation. The modalities that his lab is focused on include diffusion imaging (including DTI), functional BOLD MRI, magnetization transfer imaging, and relaxometry imaging for the characterization of brain tissues and networks. His lab has used these methods in a broad spectrum of applications ranging from animal models of disease and injury to human research to clinical practice. Specific applications include autism, multiple sclerosis, Alzheimer's disease, Parkinson's disease, brain tumors, anxiety and depression as well as age-related changes in the brain from childhood to old-age.

Ameer Pasha Hosseinbor
Department of Medical Physics
University of Wisconsin-Madison

Bessel Fourier Orientation Reconstruction: An Analytical EAP Reconstruction using Multiple Shell Acquisition in Diffusion MRI

Abstract: The ensemble average propagator (EAP) describes both the radial and angular contents of the diffusion profile, hence reflecting the complex tissue microstructure within the brain. Its estimation lies at the heart of diffusion MRI and can be done either analytically or numerically. Analytical methods include Diffusion Propagator Imaging (DPI) and Spherical Polar Fourier Imaging (SPFI). Diffusion Spectrum Imaging (DSI) estimates the EAP numerically by taking the Fast Fourier Transform (FFT) of the q-space diffusion signal. In this talk, we discuss an analytical EAP reconstruction technique, termed Bessel Fourier Orientation Reconstruction (BFOR), for hybrid, non-Cartesian sampling that we have been developing in our lab. The BFOR solution is based on the heat equation estimation of the diffusion signal for each shell acquisition and, in addition to being analytical, contains an intrinsic exponential smoothening term. We will also discuss the estimation of clinically relevant, quantitative q-space scalar measures, such as zero-displacement probability (Po) and mean square displacement (MSD), using the BFOR basis.

Bio: Ameer Pasha Hosseinbor is a PhD student at the University of Wisconsin-Madison in the department of Medical Physics, and works in the lab of Andrew L. Alexander. He received his B.S. in Physics from the University of Virginia. His dissertation research explores animal models of demyelination/dysmyelination and diffusion MRI modeling, especially with respect to multiple diffusion-weighted acquisitions.

Anqi Qiu, Ph.D.
Division of Bioengineering
National University of Singapore

Diffeomorphic HARDI Registration and Atlas Generation

Abstract: In the first part of this talk, a novel large deformation diffeomorphic registration algorithm will be introduced to align high angular resolution diffusion images (HARDI) characterized by orientation distribution functions (ODFs), elements of a statistical manifold. We embed this manifold structure and its metric into the framework of large deformation diffeomorphic metric mapping (LDDMM) and propose a mapping algorithm seeking an optimal diffeomorphism of large deformation between two ODF fields in a spatial volume domain. At the same time, this diffeomorphism locally reorients an ODF in a manner such that it remains consistent with the surrounding anatomical structure.

In the second part of this talk, we will formulate a HARDI atlas generation problem based on Bayesian modeling. We characterize a prior of the atlas in a nonlinear diffeomorphic shape space that is represented by a linear space of initial momenta of diffeomorphic geodesic flows from a fixed hyperatlas. A likelihood function is formulated as the conditional probability of observable HARDIs given hidden variables of the diffemorphism from the atlas to individual HARDI, which is modeled as a random field of ODFs. We define the atlas generation as a variational problem that maximizes a posterior distribution of the initial momentum given observable HARDI. We discuss how to solve this problem using expectation-maximization algorithm.

Bio: Qiu Anqi received her BS in Biomedical Engineering from Tsinghua University in 1999 and MS degrees in Biomedical Engineering and Applied Mathematics and Statistics from University of Connecticut in 2002 and from Johns Hopkins University in 2005, respectively. Since her Ph. D study, she has worked on the field of medical image analysis. In particularly, she has been interested in extracting anatomical and functional information from MRI images in order to identify neuroimaging biomarkers associated with neurodegenerative and neuropsychiatric diseases (e.g. schizophrenia, bipolar disorder, depression, Autism, dementia). After the graduation from Johns Hopkins University in 2006, she joined Kirby research center for functional brain imaging at Kennedy Krieger Institute as postdoctoral fellow and learned medical physics. Since the summer of 2007, she moved to Singapore and became an assistant professor of Division of Bioengineering at National University of Singapore. She started her own computational functional anatomy laboratory on the campus of the faculty of engineering. Her research focuses on the translation of mathematical modeling to quantitative medicine.

Nagesh Adluru, Ph.D.
Waisman Laboratory for Brain Imaging and Behavior,
University of Wisconsin-Madison

Large Scale Data Mining of DTI Data in Non-Human Primates

Abstract: Diffusion tensor imaging (DTI) data collected on non-human primates (NHP) has significantly lower signal-to-noise ratios (SNR). The existing neuroimaging toolsets including the acquisition protocols are heavily optimized for human data but not for NHP. However, imaging in these animals is very useful since such models of NHP present a unique opportunity for combining the imaging data with genetic expression data from brain tissue to understand some of the molecular mechanisms underlying neurological disorders. In this talk we will present challenges and opportunities in processing and analyzing large sets of DTI data collected as part of a unique study with over 600 animals. We will present tools for processing DTI data at such low SNR levels. We will then present the development of the first-of-its-kind rhesus macaque DTI atlas from 271 animals (UWRMAC-DTI271) and present evidence for the first time that tensor based registration of DTI out-performs typical T1-weighted or fractional anisotropy (FA) based registration in non-human primates. Finally, we will present our preliminary developmental models using cross-sectional data, to characterize the spatio-temporal properties of the white matter microstructure in the NHP using general linear modeling. The statistical maps from these models present evidence that the white matter microstructure properties have spatially distinct trajectories.

Bio: Dr. Nagesh Adluru is an Assistant Scientist at the Waisman Laboratory for Brain Imaging and Behavior at the University of Wisconsin-Madison and oversees much of the image analysis efforts related to diffusion MRI and tractography that happen in the lab. He received a PhD in Computer and Information Sciences from Temple University in January of 2009. His dissertation work focused on developing novel techniques for including high-level training priors into traditionally low-level computer vision problems of contour grouping and robot mapping. Since 2009, his focus of research interests have been in developing and integrating statistical and machine learning techniques such as classification and computer assisted diagnosis for large-scale pattern analysis of DTI data from a wide range of neuroscientific studies such as anxiety, autism and neuroplasticity effects of meditation. Part of his research focus is on developing and performing longitudinal analysis using advanced spatial normalization tools and statistical inference techniques such as linear mixed effect modeling. He co-developed efficient fiber tract-modeling and network modeling using tractography data with Dr. Moo K. Chung. He has also made various resource contributions, such as CAMINO-TRACKVIS and UWRMAC-DTI271 to NITRC (The source for neuroimaging tools and resources). He serves as a reviewer on a broad spectrum of journals and conferences covering topics in brain imaging, medical physics, robotics, computer vision and data mining.

Seung-Goo Kim, M.Sc.
Department of Brain and Cognitive Science
Seoul National University

What Matter Structural Connectivity Without Diffusion Tensor Imaging

Abstract: We are interested in investigating white matter connectivity using a novel computational framework that does not use diffusion tensor imaging (DTI) but only uses T1-weighted magnetic resonance imaging. This enables anatomical connectivity studies when DTI is not available. The proposed method relies on correlating Jacobian determinants across different voxels based on the tensor-based morphometry (TBM) framework. In this talk, we show the agreement between the proposed TBM-based white matter connectivity and the DTI-based white matter atlas. As an application, altered white matter connectivity in a clinical population is determined.

Bio: Seung-Goo Kim is a Ph.D. student at Seoul National University in the department of Brain and Cognitive Science. He received his B.A. in Psychology and Economics from Yonsei University and M.Sc. in Cognitive Science from Seoul National University. For the M.Sc. research, he worked on the MEG experiments on the cognitive processing on the musical chord progression in human brains, which was published in PLoS ONE. Since 2010, he has been working on problems in computational anatomy with Dr. Moo K. Chung.

Session 2. Brain Connectivity
December 3, 1:00-4:00pm

Hae-Jeong Park, Ph.D.
Yonsei University College of Medicine, Korea

Intrinsic Brain Connectivity Using fMRI and DTI

Abstract: A recent trend in brain research can best be represented by the term 'brain connectome', which describes the brain as a large complex network connected by local and inter-regional neurons. The in vivo connectome research is mainly explored in terms of anatomical connectivity defined by diffusion tensor imaging and functional connectivity defined by resting state fMRI. However, the property and meaning of functional connectivity measured during resting state is still open question. Although resting state network is generally considered to reflect intrinsic brain networks comparable to anatomical connectivity, the temporal dynamics of the resting state network is not clearly understood. The relationship between anatomical and functional connectivity remains to be answered. For these questions, we examined 24 hour resting state network changes. We also compared functional and anatomical connectivity in clinical data from patients with callosotomy and cerebral palsy. By evaluating functional connectivity changes between task performance and resting state, we will discuss the intrinsic and task-dependent networks defined by resting state fMRI.

Bio: Hae-Jeong Park, Ph.D. is an Associate Professor in the Department of Radiology and division of Nuclear Medicine, Adjunct Professors of Department of Psychiatry, Severance Biomedical Science Institute, and Biomedical Science & Engineering major, the Brain Korea 21 Project for Medical Science, Yonsei University College of Medicine. Dr. Park received his BS degree in Electrical Engineering and his MS and PhD degrees in Biomedical Engineering from Seoul National University, Seoul, KOREA, in 1993, 1995, and 2000. In 2001, he developed a novel statistical parametric mapping method of distributed current densities of high resolution event-related potential (ERP), and firstly proposed independent component analysis for cross-sectional positron emission tomography (PET) images. In the late 2001, Dr. Park joined the Laboratory of Neuroscience, Department of Psychiatry, and Surgical Planning Laboratory, Department of Radiology, Brigham and Women's Hospital, Harvard Medical School. As a research fellow of Harvard, he researched fiber tracking and quantification of diffusion tensor imaging for basic and clinical neuroscience. He firstly introduced a whole-brain fiber tractography, which was very new at that time and was chosen as cover pages of Neuroimage and Human Brain Mapping, in 2003 and 2008. He is the author of a diffusion tensor software tool, DoDTI, dated back to 2004. His research interests include brain connectome for understanding the brain mechanism, methods for multimodal neuroimaging (MRI, PET, TMS, and EEG/MEG), reading mind using real-time fMRI and brain decoding, medical image processing for surgical planning, and understanding linguistic, communicative and aesthetic brains (http://neuroimage.yonsei.ac.kr).

June Sic Kim, Ph.D.
Seoul National University Hospital

Clinical applications of brain connectivity using electrophysiological data

Abstract: The human brain is an extremely complex system and rapidly performs processing tasks. Magnetoencephalography (MEG), which measures magnetic flux produced from electrical activity by neuronal firing, has been a popular tool to analyze neural systems. This presentation contains recent researches on sensory and motor systems using MEG.

Motor cortex is coherent with muscle activity during isometric contraction. The most coherent source represents the primary motor cortex. We recently developed the robust method to identify the primary motor cortex by means of improving cortico-muscular coherence. Using this technique, cortico-muscular coherence between the primary motor cortex and the thenar muscle was compared between two conditions with and without deep brain stimulation of patients with Parkinson's disease. In the results, deep brain stimulation improved cortico-muscular coherence. And we also compared the location and the coherence level between big and little fingers during isometric contraction. The motor activities of two fingers were spatially localized according to the cortical homonculus. The cortico-muscular coherence and electromyogram were bigger during isometric contraction of thumb than little finger. Thus, the cortico-muscular coherence may reflect motor performance during isometric contraction.

The primary and secondary somatosensory cortices perform strength and location of tactile or pain stimulation. SII receives cortical connections from the ipsilateral SI, from the contralateral SI and SII via corpus callosum, as well as thalamic projections from the VPI. Whether the activation of SI and SII cortices is serial or parallel is still under debates. In the previous literatures, it is well known that SI and SII activities depend on the stimulus strength. And SII activity diminishes in the condition of short inter-stimulus interval, while the SI activity is not affected. The short inter-stimulus interval might modulate the SII cortex. We investigated the cortical activity and the connectivity between SI and SII cortices along the intensity of modulation. In the result, the peak amplitudes of contro- and ipsilateral-SII dipole activities significantly decreased according to the increasing intensity level of interfering stimulus. However, mutual information between SI and SII cortices was not significantly changed. It suggests that the SI cortex partly modulates SII cortex by the interfering stimulus and other sensory-related regions such as thalamus possibly involve the SI and SII modulation.

The other important application would be epilepsy analysis. A 3-D approach is needed to determine the presence of an epileptogenic focus in the complex structure of the cortex. However, a source localization procedure for determining the primary ictal source using ECoG has not been introduced. We applied a spatiotemporal source localization technique using the first principal vectors. A directed transfer function was then employed for the time series of the potential ictal sources to compute the causal relationship between them, from which we could identify the primary sources responsible for the ictal onset. So the primary epileptogenic focus could be identified among several candidate sources.

Bio: June Sic Kim, Ph.D., is an Assistant Professor of Department of Neurosurgery and MEG Center at Seoul National University Hospital. Kim received his Ph.D. in Department of Biomedical Engineering at Hanyang University in 2002. His dissertation work focused on developing hybrid registration for multimodal neuroimages by combining sulcal features and volume intensities. And he worked at Montreal Neurological Institute for 2 years to develop a surface extraction technique from a brain MRI. Since November of 2004, he has worked in MEG Center at Seoul National University Hospital. Now, he is interested in neuroscience using electrophysiology such as magnetoencephalography, electroencephalography, and electrocorticography. Current research topics are mainly in resting-state brain activity, motor-sensory network, and brain-machine interface.

Hyekyoung Lee, Ph.D.
Department of Nuclear Medicine, Brain and Cognitive Sciences
Seoul National University

Decomposition of Weighted Networks Using Network Filtration and Persistent Homology

Abstract: The simplest form of a network is an unweighted network and the most of graph and network theories start from the unweighted network. However, in real world networks, weighted network is more predominantly observed, where the edge weights measure the strength of relationship between nodes. In this talk, we introduce the novel framework of network filtration that decomposes the weighted network into a sequence of finite number of nested unweighted networks. The proposed new method is motivated by the persistent homology and the minimum spanning tree in the graph theory. As an application, we show how to decompose a collection of weighted brain networks using the network filtration and perform clustering on them. The propose network filtration framework outperforms seven other widely used graph theoric network measures.

Bio: Hyekyoung Lee, Ph.D. is a post doctoral Researcher in the Department of Nuclear Medicine and the Department of Brain and Cognitive Sciences at Seoul National University in South Korea. H. Lee received her B.Sc. in Electrical and Computer Engineering from Hanyang University and M.Sc. and Ph.D. degrees in Computer Science and Engineering from Pohang University of Science and Technology in 2009. During her Ph.D study, she worked on the field of machine learning and its application, EEG-based brain computer interface (BCI). Her dissertation focused on the feature extraction based on nonnegative matrix/tensor factorization to improve the performance of BCI system. Since 2009, she has focused her research in medical image analysis, especially, functional brain connectivity on PET. Her recent OHBM 2011 and MICCAI 2011 papers, which were selected for oral representation, was the first research that introduced the persistent homological framework in brain network modeling. The method was applied in finding the multi-scale connected network structures of brain in clinical populations.

Session 3. Machine Learning
December 3, 4:00-6:00pm

Vikas Singh, Ph.D.
Department of Biostatistics and Medical Informatics
University of Wisconsin-Madison

Kernel Learning for Graph Partitioning Objectives: Applications to Multi-Modality Inference Problems In NeuroImaging

Abstract: Many research studies in Neuroimaging now routinely acquire a wide variety of imaging, cognitive, demographic, and clinical data. The primary analysis task then is to meaningfully leverage this body of multi-modal data to derive novel hypotheses and/or identify patterns tied to the clinical phenomena under study. In this talk, we will first provide a brief overview of this problem in the context of identifying early manifestations of Alzheimer's disease (AD). Then, we will cover the design of inference methods to effectively leverage this data for statistical analysis. Using the popular Normalized Cuts (Ncuts) objective function, we will present mechanisms that allow a basis set of (general) similarity functions derived from different sources of information to be combined to induce NCuts favorable distributions. This procedure directly facilitates design of good affinity matrices as well as enables assessing the relative importance of different feature types (i.e., modalities) for discrimination. We will discuss how the learning problem can be formulated as a convex optimization model (and solved as a simple semidefinite program in ~20 lines of Matlab code). Finally, I will discuss why and how the model hints at the utility of incorporating higher order kernel interactions within a classical max-margin objective (such as support vector machines) for Neuroimaging applications as well as for image categorization problems in computer vision.

Bio: Vikas Singh is an Assistant Professor in the Department of Biostatistics and the Department of Computer Sciences at the University of Wisconsin Madison. Vikas graduated with a PhD in Computer Science from the State University of New York at Buffalo in 2007. His dissertation focused on reconstruction and segmentation problems in Computer Vision and Medical Imaging, which was nominated by SUNY-Buffalo for the ACM Doctoral Dissertation Award and translated into clinical software. In the last few years, Vikas has focused on new optimization and geometry based methods for early vision and machine learning problems, with a focus on applications in image categorization, object recognition, and neuroimaging. His work has received the SIIM Research Award in 2009 and an ACCV Best Application Paper award in 2010. Vikas teaches classes on AI, Medical Image Analysis, and Vision, and serves as a reviewer or program committee member in many mainstream computer vision and medical imaging conferences and journals.

Moo K. Chung, Ph.D.
Department of Statistics, Biostatistics and Medical Informatics
University of Wisconsin-Madison
Department of Brain and Cognitive Sciences, Seoul National University

Overview and Discussions

Abstract: We overview lectures and identify potential future research problems in diffusion tensor imaging and brain connectivity.

Bio: Moo K. Chung, Ph.D. (http://www.stat.wisc.edu/~mchung), is an Associate Professor in the Department of Statistics, Biostatistics and Medical Informatics at the University of Wisconsin-Madison. Also affiliated with the Waisman Laboratory for Brain Imaging and Behavior and the Vocal Tract Laboratory. As a part of the World Class University (WCU) project, he is also affiliated with the Department of Brain and Cognitive Sciences, Seoul National University. Dr. Chung received Ph.D. in Statistics from McGill University under Keith J. Worsley and James O. Ramsay in 2001. Dr. Chung's main research area is computational neuroanatomy, where noninvasive brain imaging modalities such as magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) are used to map the spatiotemporal dynamics of the human brain. His research concentrates on the methodological development required for quantifying and contrasting anatomical shape variations in both normal and clinical populations at the macroscopic level using various statistical and computational techniques. He is currently writing a 400-page research monograph on computational neuroanatomy, scheduled to be published in 2012. Recently, Dr. Chung received the Editor's Award for best paper published in Journal of Speech, Language, and Hearing Research in year 2010 for the paper that analyzed vocal tract CT images.