Probabilistic Methods in Computational Neuroscience

Jing Zhang¹, Tianming Liu¹, and Gopikrishna Deshpande²

Abstract—Probabilistic models have been successfully adopted in computational biology and bioinformatics. Recently, a number of powerful probabilistic models and methods have been developed in the field of computational neuroscience, and these effective models have significantly advanced this field. This special section aims to capture some snapshots of recent developments of probabilistic methods in the synergistic combinations of cognitive brain science, brain imaging, and neuroscience. It aims to report the latest advances in these fields to the research community working on probabilistic methods in brain imaging analysis and computational neuroscience. This special section includes five contributed articles.

Index Terms—Probabilistic models, brain imaging, computational neuroscience

1 THE SCOPE OF THIS SPECIAL SECTION

The scope of this special section includes the latest advances in the research community working on probabilistic methods in brain imaging analysis and computational neuroscience, such as

- Probabilistic models for neural spiking activity,
- Models of brain functional interaction under natural multimedia stimulus,
- Brain co-activation models under task-fMRI,
- Network modeling of brain function,
- Statistical methods for longitudinal neuroimaging data, and

It is hoped that the publication of this special section will contribute to the development and distribution of novel probabilistic methods in imaging and computational modeling of the brain.

2 CONTRIBUTIONS TO THE SPECIAL SECTION

This special section incorporates five contributed papers, which are briefly introduced as follows:

In the article “Bayesian Multiresolution Variable Selection for Ultra-High Dimensional Neuroimaging Data,” Yize Zhao, Jian Kang, and Qi Long introduce a probabilistic Bayesian method that recursively uses posterior samples to guide the inference on finer-scale variable selection. Also, this method leads to efficient Markov chain Monte Carlo (MCMC) algorithms.

In the article “Gender Identification of Human Brain Image with A Novel 3D Descriptor,” Lin Yuan, Fanglin Chen, Ling-Li Zeng, Lubin Wang, and Dewen Hu designed and applied a three-dimensional feature descriptor based on the three-dimensional weighted histogram of gradient orientation (3D WHGO) that is capable of describing complex spatial structures. Essentially, the 3D WHGO descriptor combines local information for signal intensity and global three-dimensional spatial information for the whole brain. Thus, this 3D WHGO descriptor can be considered as a probabilistic model of spatial information extraction in the structural neuroimaging domain. Based on the 3D WHGO, the authors devised and implemented a framework for the purpose of classification of three-dimensional images based on MRI. Finally, this proposed framework was used to differentiate genders at the individual level. The authors evaluated their methods by using the gender identification of individual magnetic resonance imaging (MRI) scans of a large sample of healthy adults (n = 527) across four research sites, and reported higher classification accuracy than other compared methods. It is possible that this framework may have the good potential to inform clinical practice and aid in research on neurological and psychiatric disorders.

The causal interactions among multiple neurons in the brain are crucial to understanding how neurons work to generate specific brain functions. So, it is important to develop new statistical methods and probability models for assessing causal influence between spike trains in the field of neuroscience research. In “A Copula-Based Granger Causality Measure for the Analysis of Neural Spike Train Data,” Meng Hu, Wu Li, and Hualou Liang propose a causality measure for the analysis of neural spike train data. The proposed method aims to reveal nonlinear and high-order causality in the spike trains.

In the article “Cortical Thinning and Cognitive Impairment in Parkinson’s Disease without Dementia” by
Lijun Zhang, Ming Wang, Nicholas W. Sterling, Eun-Young Lee, Paul J. Eslinger, Daymond Wagner, Guangwei Du, Mechelle M. Lewis, Young Truong, F. DuBois Bowman, and Xuemei Huang, "a flexible Bayesian model was designed to compare the cortical thickness between groups. Parkinson’s disease (PD) is a progressive neurodegenerative disorder. In this article, the cortical thickness in non-demented PD subjects was investigated. Cortical thickness was compared between groups using a flexible hierarchical multivariate Bayesian model. The correlations between brain regions were taken into account in this model. Correlation analyses among brain areas and cognitive domains showed significant group differences in the PD population.

Recent neuroimaging studies indicate that altered brain connectivity may underlie behavioral impairments in subjects with Autistic Spectrum Disorders (ASD). In the article “Complex Network Measures in Autistic Spectrum Disorders” by Joao Ricardo Sato, Maciel Calebe Vidal, Suzana de Siqueira Santos, Katlin Brauer Massirer, and Andre Fujita, various complex network based statistical measures derived from graph theory, such as centrality, clustering, degree, and entropy were used to characterize aberrations in network topology, as opposed to just pairwise connectivity differences between regions. In addition to reinforcing previously held notions such as under-connectivity in Autism, their results highlighted atypical network organization in various regions of the brain, most prominently in the cerebellum. Such investigations may provide a better understanding of the systemic alterations in brain networks in ASD. Such efforts may ultimately aid us in developing more objective biomarkers of ASD which may assist the clinician in diagnosing ASD as well as tracking treatment response.

In summary, the described five papers in this special section report their new methods, new models, and results in developing and applying statistical/probability models and methods to different areas of computational neuroscience research, such as analysis of neural spike train data, high dimensional neuroimaging data, and for different brain conditions such as Parkinson’s disease and Autistic Spectrum Disorders.

Jing Zhang
Tianming Liu
Gopikrishna Deshpande

Guest Editors

Jing Zhang received the PhD degree from Harvard University, USA, in 2009. She is currently an assistant professor at Georgia State University. From 2009 to 2010, she was a postdoc at Harvard University. From 2010 to 2014, she was an assistant professor at Yale University. She is research interests include bayesian inference on complicated interactions, big data analysis, neuroimage analysis, brain mapping, functional brain imaging analysis, statistical genetics, epigenetics, computational virology, bayesian network, graph models, and computational neuroscience. She has authored/co-authored over 40 peer reviewed journal/conference papers. She received Seessel Awards at Yale University in 2010 to 2013, and the Brains and Behavior Seed Grant from Georgia State University in 2015-2016.

Tianming Liu is a distinguished research professor of computer science at The University of Georgia. His research interest focuses on brain imaging and mapping. He has published over 280 peer-reviewed papers in this area. He is the recipient of the NIH Career Award and the NSF CAREER award, both in the area of brain mapping.

Gopikrishna Deshpande received the MS degree in electrical communication engineering from the Indian Institute of Science Bangalore, India (2001-2003) and the PhD degree in biomedical engineering from the Georgia Institute of Technology, USA (2003-2007). He is an associate professor of electrical and computer engineering and heads neuroimaging activities at the AU MRI Research Center in Auburn University, USA. He is also an affiliated faculty in the Department of Psychology at Auburn University. Before moving to Auburn, He was first a post-doc and then a research faculty at the Biomedical Imaging Technology Center, Emory University (2007-2010), USA. He has published more than 75 peer-reviewed journal papers in the field of signal processing, neuroimaging, and brain connectivity. He has received more than $ 4 million in research funding from DARPA and NIH. He is a member of IEEE.