BIOGRAPHICAL SKETCH

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NAME	POSITION TITLE
Chung, Moo	Associate Professor, Biostatistics and Medical Informatics
eRA COMMONS USER NAME mkchung	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
McGill University	B.Sc	1995	Applied Mathematics
University of Toronto	M.Sc.	1997	Mathematics
McGill University	Ph.D.	2001	Statistics(Neuroimaging)

A. Personal Statement

I am an associate professor in the Department of Biostatistics and Medical Informatics. I received Ph.D. in Statistics (neuroimaging) from McGill University under Keith J. Worsley in 2001. I participated the World Class University (WCU) project and was affiliated with the Department of Brain and Cognitive Sciences, Seoul National University for three years between 2009-2011 as an associate professor. My main research area is computational neuroanatomy, where non-invasive medical imaging modalities such as magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) are used to map spatiotemporal dynamics of the human brain. Computational neuroanatomy deals with the computational problems arising from the quantification of the structure and the function of the human brain. My research has been concentrated on the methodological development of quantifying neuroanatomical shape and network variations in both normal and clinical populations using various computational and statistical techniques. I also collaborate extensively with investigators in the School of Medicine and Public Health in the area of medical image analysis and methods development in brain imaging. Most of collaborations also require interacting, training and supervising students on medical imaging related projects and providing consults to collaborators. The collaboration with the Vocal Tract Laboratory won the Editor's Award for best paper published in Journal of Speech, Language, and Hearing Research in year 2011 for analyzing vocal tract CT images. I also received the Vilas Associate Award for years 2014-2015 for new topological data analysis applied to medical images. I have published two books on brain image analysis in 2013: Computational Neuroanatomy: The Methods, and Statistical and Computational Methods in Brain Image Analysis and in the process of writing the third book titled as Brain Network Analysis. Personal webpage can be found at http://www.stat.wisc.edu/~mchung/.

B. Positions and Honors

Positions and Employment

1999-2001	Lecturer, McGill University, Montreal, Quebec, Canada
2001-2007	Assistant Professor, Department of Statistics
2002-2007	Assistant Professor, Departments of Statistics and Biostatistics and Medical Informatics, University of Wisconsin, Madison, WI
2009-2011	Associate Professor, Department of Brain and Cognitive Sciences, Seoul National University, Korea
2007-present	Associate Professor, Departments of Statistics and Biostatistics and Medical Informatics, University of Wisconsin, Madison, WI

Honors

1995-1997	NSERC Fellowship, University of Toronto
1996-1998	Open Fellowship, University of Toronto
1999-2001	ISM Fellowship, McGill University, Montreal, Quebec, Canada
2000	NIH Traveling Graduate Stipend Award for in Human Brain Mapping Conference
2011	Editor's Award for the best paper in Journal of Speech, Language, and Hearing Research
2014-2015	Vilas Associate Award, University of Wisconsin-Madison
2016-2019	Brain Initiative Award

C. Contributions to Science

1. My main contribution has been in the area of **computational neuroanatomy**, where noninvasive brain imaging modalities such as magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) are used to map spatiotemporal dynamics of the human brain. Computational neuroanatomy is at the intersection of statistics, mathematics, computer science and neuroscience and deals with the computational problems arising from the quantification of the structure and the function of the human brain at macroscopic levels using various computational techniques. Major challenges are caused by the massive amount of nonstandard, high-dimensional, non-Euclidean imaging data that are difficult to analyze using standard techniques. This requires new computational solutions in addressing more complex scientific hypotheses. I have made substantial contributions in formulating and developing voxel-wise brain morphometric techniques mainly referred to as deformation-based morphometry (DBM) and tensor-based morphometry (TBM) [a,b,d]. In trying to model shape variations at voxel-level, it is not clear what sort of image features should be analyzed. [a] was the first paper that modeled and analyzed the distribution of tensor features such as the Jacobian determinant and divergences of brain deformation systematically in a unified statistical framework. These features are essential in measuring the tissue growth and atrophy at each voxel. The paper influenced other researchers to further investigate on the distribution of the Jacobian determinant and many papers have been written on this topic. The technique introduced in the paper was applied in quantifying the patterns of brain growth in longitudinally collected MRI of developing children. [b] extends the idea of the Jacobian determinant in a generalized tensor formulation and were able to show how to quantify surface specific growth locally. Recently I wrote a 403-page research monograph summarizing computational neuroanatomy [c].

   a. Chung, M.K., Worsley, K.J., Paus, T., Cherif, C., Giedd, J.N., Rapoport, J.L, Evans, A.C. 2001. A unified statistical approach to deformation-based morphometry, NeuroImage 14:595-606.
   b. Chung, M.K., Worsley, K.J., Robbins, S., Paus, P., Taylor, J., Giedd, J.N., Rapoport, J.L., Evans, A.C. 2003. Deformation-based surface morphometry with an application to gray matter Deformation, NeuroImage. 18:198-213.
   c. Chung M.K., 2013. Computational Neuroanatomy: The Methods, World Scientific Publishing.
   d. Hanson, J. Chung, M.K., Avants, B., Shirtcliff, E., Gee, J., Davidson, R.J. 2010. A tensor-based morphometry investigation of brain structure and behavioral risk. Journal of Neuroscience. 30:7466-7472 PMCID: PMC2893146

2. A lot of anatomical features that characterize brain shape variability can only be measured relative to a cortical surface. Hence it is necessary to develop **surface-based smoothing** techniques for increasing sensitivity and specificity of cortical surface data. A significant hurdle in this area had been caused by the lack of surface-based analysis techniques that incorporate the non-Euclidean geometric nature of the cortical surface. I have proposed the concept of smoothing anatomical measurements along tissue boundaries for this purpose [a-d]. I have developed two novel surface-based regression techniques for smoothing measurements along the cortical surfaces. The first technique referred to as diffusion smoothing utilizes the concept of an isotropic heat flow as a way to smooth densely sampled anatomical measurements such as cortical thickness, curvatures and local cortical area [a,b]. The algorithm performs the heat diffusion with the surface measurments as the initial contion by solving a partial differential equation (PDE) numerically. The second technique referred to as heat kernel smoothing was developed in response to the numerical shortcomings of diffusion smoothing [c,d]. The drawbacks of diffusion smoothing are the complexity of numerically solving the PDE and the numerical instability that depends too much on the smoothness of anatomical boundary. In heat kernel smoothing, the analytically unknown nonlinear heat kernel is approximated linearly and smoothing is performed as the iterative convolution in a spatially adaptive fashion. Since the introduction in 2005, heat kernel smoothing spurred many discussions and papers by other researchers. These two methods became standards in filtering out cortical surface noise and have been implemented in various brain analysis packages such as FreeSurfer, AFNI and SurfStat. Numerous neuroimaging laboratories around the world are using my codes.

   a. Chung, M.K., Worsley, K.J., Robbins, S., Evans, A.C. 2003. Tensor-based brain surface modeling and analysis, The proceeding of IEEE Conference on Computer Vision and Pattern Recognition (CVPR) Vol. I 467-473.
   b. Chung, M.K., Taylor, J. 2004. Diffusion smoothing on brain surface via finite element method, IEEE International Symposium on Biomedical Imaging (ISBI). 562.

c. Chung, M.K., Robbins,S., Dalton, K.M., Davidson, Alexander, A.L., R.J., Evans, A.C. 2005. Cortical thickness analysis in autism via heat kernel smoothing. NeuroImage 25:1256-1265.
d. Chung, M.K., Robbins, S., Evans, A.C. 2005. Unified statistical approach to cortical thickness analysis. Information Processing in Medical Imaging (IPMI). 3565:627-638.

3. I worked on developing a more fundamental and robust **weighted Fourier series** for representing and analyzing complex surface measurements. As in any new emerging research field, many techniques in the field are borrowed and pieced together in an ad-hoc fashion from many branches of computational science. Thus, sometimes there is a lack of single unifying framework that connects the sequence of procedures in computational neuroanatomy. Having a single coherent computational framework speeds up computation and makes it easy to set up a more complex statistical model. My research in this direction has resulted in new technique referred to as *weighted spherical harmonics* (SPHARM) [a,b]. The weighted-SPHARM incorporates parameterization, image smoothing, surface registration and statistical inference in a single mathematical framework while reducing the Gibbs phenomenon (ringing artifacts) associated with the traditional approach. This novel technique and related applications have been well received by other researchers in the field and resulted in an invited paper to IEEE transactions on medical imaging [a]. In fitting SPHARM to brain surfaces, it was necessary to estimate more than 15,000 spherical Fourier coefficients simultaneously. By a careful investigation of the properties of spherical harmonics, we were able to come up with a new faster algorithm referred to as *iterative residual fitting* (IRF) [a]. The weighted-SPHARM is further extended to the Laplace-Beltrami eigenfunction based regression framework on manifolds that corresponds to isotropic diffusion for the first time [c]. Further extending SPHARM methods, we were able to generalize to 4D SPHARM on 4D hypersphere [4].

a. Chung MK,Dalton KM, Shen L, Evans AC, Davidson RJ. 2007. Weighted Fourier series representation and its application to quantifying the amount of gray matter. IEEE Transactions on Medical Imaging 26:566-581.
b. Chung, M.K., Worsley, K.J., Nacewicz, B.M., Dalton, K.M., Davidson, R.J. 2010. General multivariate linear modeling of surface shapes using SurfStat. NeuroImage. 53:491-505. PMCID: PMC3056984
c. Seo, S., Chung, M.K., Voperian, H.K. 2010. Heat kernel smoothing using Laplace-Beltrami eigenfunctions. Medical Image Computing and Computer Assisted Intervention (MICCAI). 6363:505-512. PMCID: PMC2972584
d. Hosseinbor, A.P., Chung, M.K., Schaefer, S.M., van Reekum, C., Peschke-Schmitz, L., Sutterer, M., Alexander, A.L., Davidson, R.J. 2013. 4D Hyperspherical harmonic (HyperSPHARM) representation of multiple disconnected brain subcortical structures, Medical Image Computing and Computer Assisted Intervention (MICCAI). 8149:598-605 PMCID: PMC4033314

4. The field of computational neuroanatomy is fairly active and mature now. However, many of the current techniques in computational neuroanatomy are geometric in nature and assume topological invariance between shapes and deformations. Such approaches are not applicable for objects with changing topology. There are numerous such examples from longitudinal development to cancer growth. For example, an infant may have about 300-350 bones at birth but an adult has 206 bones. These bones fuse together as the infant grows. This type of topological change cannot be modeled properly with current shape models that assume topological invariance. Also, currently popular diffeomorphic image registration frameworks do not work for matching objects with different topology. So I pursued these types of topology-oriented image analysis problems, where topological invariance is *not* assumed in performing statistical inference and shape analysis. Around 2008, I started working on **persistent homology**, and its critical application to brain imaging data for the first time. Persistent homology is a new area of computational topology that tries to understand the underlying high-dimensional structure from low-dimensional local topological structure. Instead of looking at shapes and images at a fixed scale, as usually done in traditional approaches, persistent homology observes the changes of topological features over different scales (called filtration values) and finds the most persistent topological features that are robust under noise perturbations. Topological invariants such as the Euler characteristic and Betti numbers ($\beta_0, \beta_1, \cdots$) have been the main features of interest in persistent homology. By 2009, there had been many theoretical advancements in the field, but large-scale real-world applications beyond toy examples to clearly demonstrate its usefulness and power were lacking. So the concept had been a theoretical curiosity in medical imaging fields. In this context, I wrote the first paper on the application of persistent homology to MRI using the cortical thickness of the human brain [a]. The method is used in

discriminating the topological patterns of cortical thickness between autism and normal controls. The method presented in the paper was later applied in characterizing Alzheimer's disease and extended into a journal version [b]. Later we were able to extend its applicability to brain networks [c,d].

a. Chung, M.K., Bubenik, P., Kim, P.T. 2009. Persistence diagrams of cortical surface data. Information Processing in Medical Imaging (IPMI). Lecture Notes in Computer Science (LNCS). 5636:386-397
b. Pachauri, D., Hinrichs, C., Chung, M.K., Johnson, S.C., Singh, V. and ADNI. 2011. Topology-based kernels with application to inference problems in Alzheimer's disease. IEEE Transactions on Medical Imaging. 30:1760-1770 PMCID: PMC3245735
c. Lee, H., Kang, H.K., Chung, M.K., Kim, B.-N., Lee, D.S. 2012. Persistent brain network homology from the perspective of dendrogram, IEEE Transactions on Medical Imaging. 31:2267-2277
d. Lee, H., Chung, M.K., Kang, H., Lee, D.S. 2014. Hole detection in metabolic connectivity of Alzheimer's disease using k-Laplacian, Medical Image Computing and Computer Assisted Intervention (MICCAI). 8675:297-304

5. Any application of compressed sensing (CS) and sparse models is governed by a tuning parameter λ by which we can adjust the number of significant edges in the estimated **brain network** [a,b,c,d]. The resulting network $G(\lambda)$ can be viewed as a function of λ. After working on this problem for a while, I discovered the following monotonicity property. Under some conditions, $G(\lambda_1) \subset G(\lambda_2) \subset \cdots$ for $\lambda_1 > \lambda_2 > \cdots$. Connecting to my other work in persistent homology, it turns out that this type of nested subset relation is called Rips filtration and is the basic data structure in persistent homology. Once we represent a network as a series of nested sub-networks, we can borrow many mathematical tools from persistent homology. As a result, we have now connected three different distinct objects (persistent homology, CS, networks) and integrated them into a single coherent mathematical framework. We were successful in applying this new topological framework to PET-based brain networks in discriminating attention deficit hyperactivity disorder (ADHD) children from normal control subjects [a,b]. The method was able to discriminate the groups better than 8 existing well-known graph theoretic measures [a].

a. Lee, H., Lee, D.S., Kang, H., Kim, B.-N., Chung, M.K. 2011. Sparse brain network using penalized linear regression. Proceedings of SPIE. 7965, 796517
b. Lee, H., Lee, D.S., Kang, H., Kim, B.-N., Chung, M.K. 2011. Sparse brain network recovery under compressed sensing. IEEE Transactions on Medical Imaging. 30:1154-1165
c. Chung, M.K., Hanson, J.L., Lee, H., Adluru, N., Alexander, A.L., Davidson, R.J., Pallak, S.D. 2013. Persistent Homological Approach to Detecting White Matter Abnormality in Maltreated Children: MRI and DTI Multimodal Study. Medical Image Computing and Computer Assisted Intervention (MICCAI). 8149:300-307
d. Qiu, A., Lee, A., Tan.M., Chung, M.K. 2015. Manifold learning on brain functional networks in aging, Medical Image Analysis 20:52-60.

A full list of more than 120 peer-reviewed publications can be found at
http://www.stat.wisc.edu/~mchung/publications.html

D. Research Support

Ongoing Research Support

R01 EB022856 (M. Chung, PI) 9/26/17 - 6/30/19 NIH
BRAIN Initiative: Theories, Models and Methods for Analysis of Complex Data from the Brain
The goal of this project is to develop algorithms and open-source software for determining the heritability of large-scale brain networks using DTI, fMRI and MRI.

R01 AA022856 (M. Schneider, PI) 9/15/11 – 8/31/17 NIH
Fetal Alcohol in Monkeys: Dopamine and Behavior
The project deals with longitudinal PET imaging study of primates in understanding the mechanism of prenatal stress and moderate level prenatal alcohol exposure effects.
Role: Statistician

R01 DC006282 (H. Vorperian, PI) 7/01/14 - 6/30/19 NIH
MRI and CT Studies of the Developing Vocal Tract
This project combines imaging, acoustic analysis of speech, acoustic reflection or acoustic pharyngometry data, and VT modeling in an investigation on the development of the supra-laryngeal speech apparatus throughout the lifespan.
Role: Co-Investigator

P01 AG020166 (C. Ryff, PI) 07/15/11-06/30/18 NIH
Integrative Pathways to Health and illness. The goal of this project is to investigate the influence of socio-demographic, psychosocial, and behavioral factors on health and well-being from early adulthood to later life.
Role: Co-Investigator

UL1 TR000427 (M. Drezner, PI) 06/01/13-05/31/18 DHHS/NCRR
Institute for Clinical and Translational Research. The Biostatistics and Research Ethics Resource provides collaborative support during design, conduct and analysis phases of research projects.
Role: Co-Investigator

P50 MH100031 (R. Davidson, PI) 09/01/13-08/31/18 NIMH NIH

Early Neurodevelopmental Origins of Anxiety. The goal of this Center is to investigate the underlying brain circuits and molecular pathways that contribute to anxious temperament early in life.

Completed Research Support

R01 MH061285 (S. Pollak, PI) 8/1/2012 - 5/31/17 NIH
Emotion processing: Risk for psychopathology. The goal is to understand the effects of abuse on children's brain-behavioral development. This project will harness behavioral, cognitive neuro-physiological, anatomical, genetic, and neuro-endocrine measures to clarify the developmental mechanisms linking early stress in childhood with the emergence of mental health problems in adolescence.
Role: Co-investigator

1R01MH081884-01A1 (Ned Kalin, PI) 07/1/08-2/28/15 NIH/NIMH

Brain Mechanisms mediating Genetic Risk for Anxiety and Depression
The goal of the proposed experiments is to identify genetic factors that play a major role in the development of human anxiety and affective disorders.
Role: Co-investigator

1 P01 AT004952 (Richard Davidson, PI) 09/30/08 - 05/31/13 NIH
Wisconsin Center for the Neuroscience and Psychophysiology of Meditation
The goal is to establish a center for neuroscience and psychophysiology of meditation focusing on brain mechanisms and peripheral correlates of mindfulness-based meditation and meditation designed to cultivate compassion and loving kindness.
Role: Co-investigator

1 R01 MH080826 (A Alexander, PI) 8/1/07-8/31/12 NIH
Atypical Late Neurodevelopment in Autism: A Longitudinal MRI and DTI Study
The goal of is to understand longitudinal brain mechanism from childhood into adulthood in autism, and how dynamic brain and clinical phenotype are related.
Role: Co-investigator