Research Statement

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My areas of expertise are centered around imaging and computer vision, with particular interest in mathematical models for medical image processing. Recently, I have focused on medical imaging, particularly segmentation, registration, and noise reduction, including modern techniques for Diffusion Tensor Image (DTI) processing. I also have good knowledge of most computer vision such as dynamic vision (tracking), 3D modeling from uncalibrated images and video (reconstruction of geometry and appearance from images).

Computer vision. On the mathematical side, my focus is on PDE and variational methods, where partial differential equations (PDEs) are used to solve imaging problems and geometric methods. Variational methods are currently a hot topic in imaging. They have several advantages over conventional direct algorithmic solution techniques. Problems are specified equationally in an energy or error functional, which is often easier than directly writing down a solution algorithm. Solution methods are instead derived based on a solid mathematical theory and finally solved by general numerical PDE solvers. Hence, this framework brings the power of some of the most well studied mathematical theories and numerical methods into the realm of imaging. As an example, we found that the conventional finite difference scheme used to solve the second order diffusion PDE in the anisotropic tumour growth model [Jbabdi 2005] is numerically unstable when using real DTI data [MMBIA'10]. We propose a new solution based on a first-order PDE that can be numerically solved in a stable and consistent way [MIA'11,MICCAI'09]. The use of variational methods in computer vision was pioneered at French National Research Institute of Computer Science (INRIA). While a postdoctoral fellow there, I had the opportunity to learn from top researchers in the field. On my return to Canada, I have started to apply this to medical imaging.

Another side of my research is related to shape and appearance reconstruction for 3D modeling from uncalibrated images and video [ICCV'11, ECCV'06,'02, Eurographics'02, bookchapter'10]. Through the multitude of related vision and robotics projects that I worked on, I have deeply understood the mathematical theory of image formation and dynamics. I think there is a great potential but still limited research in applying the 3D modeling techniques in the medical field.

Medical image analysis On the application side, my recent work is in medical image analysis. With the development of medical imaging hardware, advanced image analysis is increasingly essential in diagnosis, treatment planning and follow-up assessment of disease. In the past decade, new mathematical imaging methods have been adapted and developed to deal with 3D, 4D (3D temporal) or tensor medical data. These methods provide quick processing and interpretation of medical imaging allowing personalized therapy and statistical studies for a large population. These mathematical models of medical image analysis became the focus of my research in the last years. I have been involved in three main collaborative projects.

Brain tumor segmentation and growth prediction project involves a collaboration between the Cross Cancer Institute (CCI) [Dr. Albert Murtha], BTAP (Brain Tumor Analysis Project) group from Computer Science, UofA and Mark Schmidt from UBC. As part of this project, together with two graduate students that I co-advised, we designed and implemented automatic and semi-automatic segmentation methods for brain tumors in MRI images. During my PIMS postdoc, I focused on developing a mathematical model for growth prediction based on Diffusion Tensor Images in collaboration with my PDF supervisor Prof. John Bowman and his colleague Prof. Thomas Hillen from Mathematics Department, UofA. We proposed a solution based on PDE diffusion methods. My recent research visit at the Technical University Munich opened a new collaboration with Prof. B. Menze, one of the leading researchers in the field of brain tumour analysis and co-organizer of the

BRATS (Brain Tumor Image Segmentation Challenge 2012-2014). I had the opportunity to both interact with him and his group and co-teach one of his seminars. This project resulted in several publications in top medical imaging venues [MIA'11, IJCARS'11, MICCAI'09], an invited talk at the Canadian Mathematical Society meeting in 2011, as well as a MSc thesis price for student Parisa Mosayebi.

Estimation of patients body mass composition from CT images project is a collaboration with Prof. Vickie Baracos also from CCI and a Canadian company Tomovision. With the help of a research assistant and a PhD student that I have supervised, we completed the design and implementation of a very accurate segmentation system that is currently used in CCI and is planned to be translated into a commercial product [with Tomovision]. As part of this project we developed a novel image registration method based on the random walker algorithm. This method was well received by the medical image analysis community [MICCAI'11,'13 papers and an invited talk at the FIELDS conference in Toronto 2011].

Imaging biomarkers in MRI images of multiple sclerosis patients is a more recent collaboration with Prof. A. Wilman from Biomedical Engineering, Dr. G. Blevins and Dr. R. Camicioli from the Division of Neurology, UofA. The project involves segmentation and shape analysis of subcortical gray matter. As part of this project, I develop new methods for brain segmentation using quantitative MRI imaging and well as robust statistical methods able to identify localized brain differences between MS patients and controls.

Grant applications I hold a NSERC discovery grant since 2011. The grant topic is a unified framework for a continuous shape manifold with applications in medical image segmentation, atlas generation and shape analysis. This grant funded PhD student Karteek Popuri and two undergraduate summer RAs. The collaborative work with people in CCI opened the opportunity for two research grants applications. For the muscle segmentation project, we submitted a collaborative NSERC-CIHR grant with a translational team of three researchers. For the tumor growth prediction project we have submitted an ACRI Operating grant application with a team of four University of Alberta professors and one medical collaborator. Unfortunately, both applications were rejected but we are now preparing resubmissions.

Planned research program The emphasis on my research program is on medical image analysis. We saw large investments in expansive medical scanners in our province, but very little development on the analysis side. Most local medical research groups (BME, Neurology, Psychiatry) are using canned software, thus missing the recent advances in medical image analysis field that would allow more sophisticated and targeted analysis of their data.

As an immediate goal, through an NSERC Engage grant followed by an NSERC-CIHR collaborative grant, we like to facilitate the industry translation opportunity for our muscle segmentation software [with Dr. Vickie Baracos, CCI]. There is interest from the Canadian company Tomovision in commercializing our software.

The brain tumour project is also a very promising collaboration. There is great MRI and DTI data both locally [Dr. Albert Murtha from CCI] and in Calgary [neuroArm project: Prof. Garnett Sutherland and Dr. Sonny Chan]. There is broad interest in studying tumour growth from the these research groups and expertise in mathematical modeling from our colleagues in Math [Dr. T Hillen and Dr. J. Bowman].