LDDMM Software Suite: an evolving BIRN technology

Anthony Kolasny, Timothy Brown, Michael Bowers, Joseph Hennessey, Youngser Park, Faisal Beg, Yan Cao, Joan Glaunes, Anqi Qiu, Marc Vaillant, Malini Hosakere, Carey Priebe, Laurent Younes, Tilak Ratnanather, Michael Miller

• Computational Anatomy (CA) [5,9] is the mathematical and computational analysis of biomedical shape and form. CA has three parts:

i. anatomical manifold generation via segmentation of known structures
ii. anatomical manifold quantification via morphometric comparison
iii. disease detection and diagnosis.

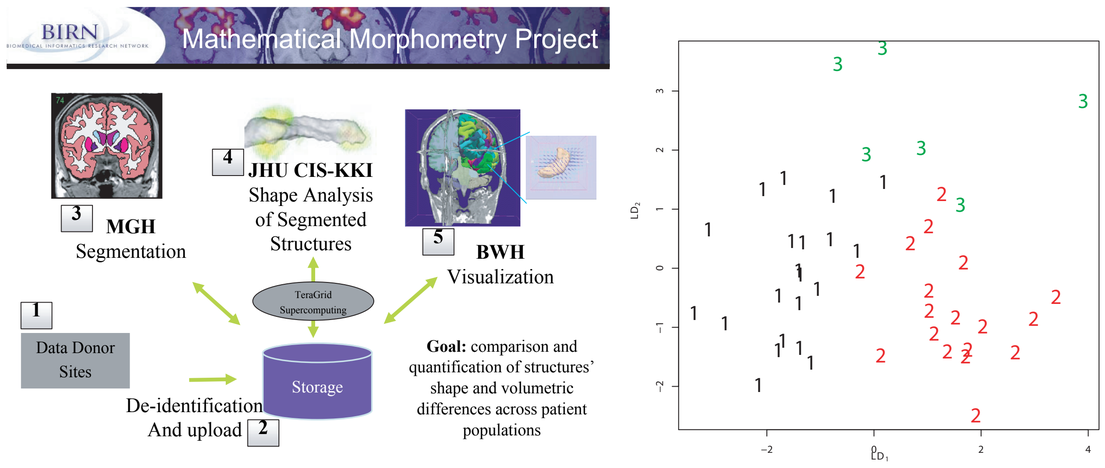
• CA synthesizes D'Arcy W. Thompson's seminal ideas [10] in which transformations of local coordinate systems are used to compare anatomical structures.

• A key component of CA is the Large Deformation Diffeomorphic Metric Mapping (LDDMM) algorithm [2] that provides a framework for a hierarchy of mappings of embedded structures such as landmarks, gyral/sulcal curves, cortical surfaces, scalar and diffusion image volumes.

• Such a sequence of mappings ensures that connected sets and disjoint sets remain connected and structure and topology remain preserved.

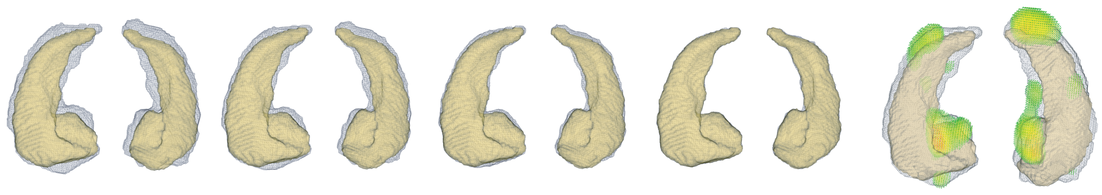
• LDDMM can be used to study anatomical structures at various scales from brain structures to sub-microscopic structures, and is being used in Morphometry BIRN and Mouse BIRN projects.

• LDDMM has been extended to LDDMM-Landmark, LDDMM-Curve, LDDMM-Surface and LDDMM-DTI.



Morphometry BIRN Top left shows the dataflow for the shape analysis-processing pipeline: 1) structural MRI data is uploaded from WashU, 2) de-identified locally, 3) semi-automated subcortical segmentation is done at MGH, 3) shape analyses of segmented hippocampus data is done at JHU, and 4) visualization of combined morphometric results is done at BWH. Top right shows analysis of LDDMM generated metric distances between hippocampi in a study of Alzheimer's via a Linear Discriminant Analysis 2D scatter plot [6]. Class labels are represented by Nondemented Controls (1), Alzheimer's Disease (2) and Semantic Dementia (3).

Teragrid resources at SDSC and NCSA via GPFS-WAN were used to analyze hippocampi from 101 subjects. Shown below on the left is a sequence of deformed pair of hippocampi from template to target at time instants of t = 0, 10, 15 and 20; the right most panel shows velocity vector information highlighting significant hippocampal deformation areas or brain regions that differ between the control and Alzheimer's scans.



Mouse BIRN. Figure below shows how LDDMM transforms a template dendrite spine towards a target spine in a shape analysis of spines from animal models of FragileX and Parkinson's Disease. Preliminary results suggest that after accounting for volume, length, surface area and type of spine, there is significant difference in the condition of the spines ($p<0.03$) [1]. Note how changes in shape are indicated by velocity vectors.

References:

[1] G. M. Aldridge, T.N.Tasky, J. T. Ratnanather, M. E. Martone, M. Terada, M. F. Beg, L. Fong, E. Ceyhan, A. E. Kolasny, T. J. A. Brown, E. L. Cochran, S. J. Tang, D. V. Pisano, M. Vaillant, M. K. Hurdal, J. D. Churchill, W. T. Greenough, M. I. Miller and M. H. Ellisman, Semi-automated shape analysis of dendrite spines from animal models of FragileX and Parkinson's disease using Large Deformation Diffeomorphic Metric Mapping, Society for Neuroscience Annual Meeting (2005).

[2] M. F. Beg, M. I. Miller, A. Trouve and L. Younes, Computing Large Deformation Metric Mappings via Geodesic Flows of Diffeomorphisms, International Journal of Computer Vision, 61 (2005), pp. 139-157.

[3] Y. Cao, M. I. Miller, S. Mori, R. L. Winslow and L. Younes, Diffeomorphic Matching of Diffusion Tensor Images, 2006 Conference on Computer Vision and Pattern Recognition Workshop (CVPRW'06), 2006, pp. 67.

[4] J. Glaunes, A. Qiu, M. I. Miller and L. Younes, Large Deformation Diffeomorphic Metric Curve Mapping, IEEE Trans Pattern Analysis and Machine Intelligence, submitted (2007).

[5] U. Grenander and M. I. Miller, Computational Anatomy: An Emerging Discipline, Quart. App. Math., 56 (1998), pp. 617-694

[6] J. Jovicich, M. F. Beg, S. Pieper, C. Priebe, M. Miller, R. Buckner and B. Rosen, Biomedical Informatics Research Network: Integrating Multi-Site Neuroimaging Data Acquisition, Data Sharing and Brain Morphometric Processing, in A. Tsymbal and P. Cunningham, eds., 18th IEEE Symposium on Computer-Based Medical Systems (CBMS'05), IEEE, Dublin, Ireland., 2005, pp. 288-293.

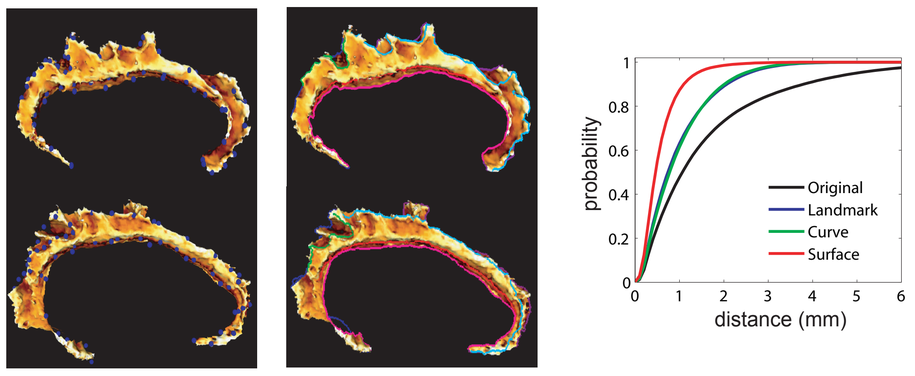
[7] C. B. Kirwan, C. Jones, M. I. Miller and C. E. L. Stark, High-resolution FMRI investigation of the medial temporal lobe., Human Brain Mapping, in press (2007).

[8] M. I. Miller, M. F. Beg, C. Ceritoglu and C. Stark, Increasing the power of functional maps of the medial temporal lobe by using large deformation diffeomorphic metric mapping, Proc Natl Acad Sci U S A, 102 (2005), pp. 9685-90.

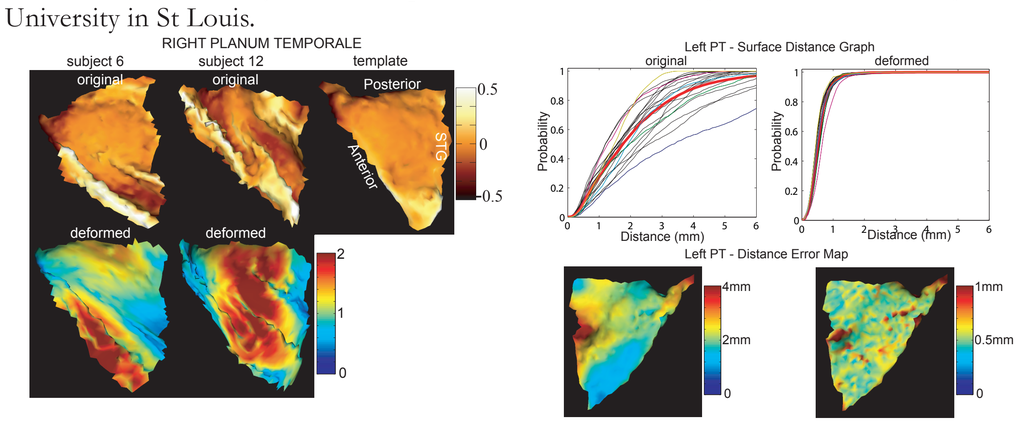
[9] M. I. Miller and A. Qiu, The Emerging Discipline of Computational Functional Anatomy, IEEE Trans Med Imaging, in press (2007).

[10] D. W. Thompson, On Growth and Form, Cambridge University Press, 1917.

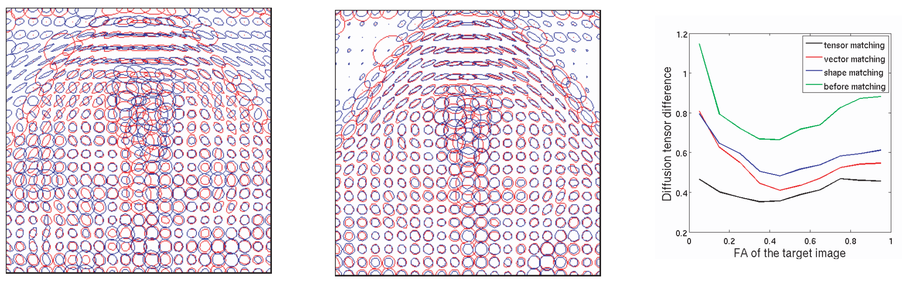
[11] M. Vaillant, A. Qiu, J. Glaunes and M. I. Miller, Diffeomorphic Metric Surface Mapping in Subregions of the Superior Temporal Gyrus, Neuroimage, in press (2007).



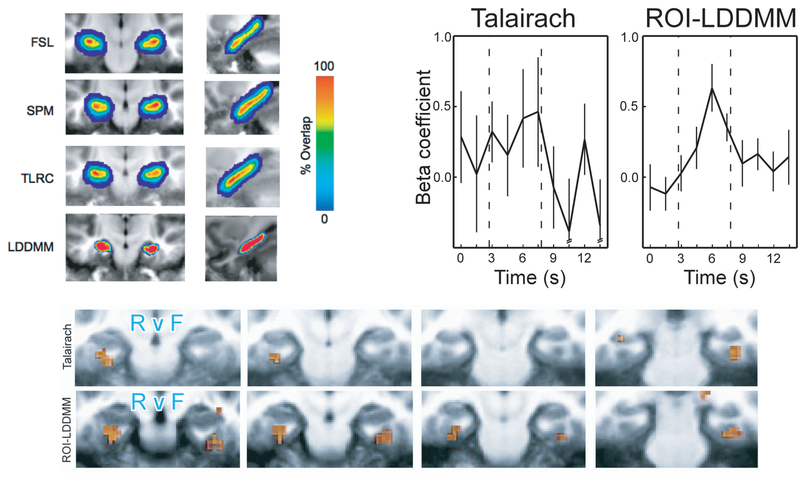
LDDMM-Landmark and LDDMM-Curve [4]: landmarks (left) and curves (right) placed on template (top) and target (bottom) cingulate surfaces. Increasing sub-voxel accuracy of LDDMM algorithms is indicated by the averaged CDF for surface distances between 130 left cingulate surfaces from a study of schizophrenia at the laboratory of Dr. Csernansky, Washington University in St Louis.



LDDMM-Surface [11]: target and template planum temporale (PT) cortical surfaces are colored by curvature information while deformed surfaces are colored by the degree of deformation. Red and blue respectively denote stretched and compressed regions after matching. CDFs indicate sub-voxel accuracy after mapping of 20 surfaces. Distance error maps intuitively show how far original (left) and deformed (right) surfaces are from the template surface respectively. Data from the laboratory of Dr. Barta, Johns Hopkins University School of Medicine.



LDDMM-DTI [3]: tensor distribution of a region in one slice before (left) and after (middle) mapping (blue and red indicate template and target respectively). The graph compares the difference between template and target tensors before and after different matching schemes. LDDMM-DTI improves quality in areas with low FA values.



Computational Functional Anatomy of the Medial Temporal Lobe (MTL) [7,8]: Above left shows coronal (left) and sagittal (right) cropped views of segmentations of MTL averaged from 15 subjects with different alignment schemes. Top right shows hemodynamic responses represented by the beta coefficient of functional response from a 39-voxel (609 mm^3) cluster within the right perirhinal cortex. Lower panel shows areas of significant functional activity during the recognition memory task associated with incidental encoding (R v F: remembered vs forgotten), showing as colored overlays on coronal slices through the MTL.

The above examples demonstrate the impact of LDDMM and its extensions on the precise quantification of anatomical structure and function in disease.

Research supported by: P41 RR15241-01A1 (NIH), P41 RR15241-02S1(BIRN) and DMS-0456253(NSF)