PHYSICAL MATH SEMINAR

Machine Learning for Neuroimage Registration

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ABSTRACT:

Aligning brain images from magnetic resonance imaging (MRI) is a core challenge in neuroscience. The alignment problem, known as registration, allows us to compare anatomy across individuals, build population averages, and study how structure and function varies with disease or development. Registration is posed as a nonlinear optimization problem with two competing objectives: aligning brain structure while maintaining a smooth deformation field.

Machine learning has emerged as a powerful alternative to classical optimization-based registration, achieving both faster and more accurate alignment. In this talk, I will first introduce the use of machine learning for neuroimage registration, then present two of our recent frameworks extending this paradigm.

We first propose MultiMorph, a fast and efficient method for constructing anatomical atlases on the fly. Atlases capture the canonical structure of a collection of images and are essential for quantifying anatomical variability across populations. MultiMorph is a feedforward model that rapidly produces population-specific atlases in a single forward pass for any 3D brain dataset, without any fine-tuning or optimization. The model is based on a linear group-interaction layer that aggregates and shares features within the group of input images.

Next, I will describe recent work tackling the problem of jointly registering the cortical surface of the brain and the interior volume. While conventional volumetric registration methods such as MultiMorph capture global brain alignment, they are limited in aligning cortical structure. The cortex is a highly folded, curved surface best represented as a triangular mesh. Euclidean alignment methods fail to capture this geometry. We propose a framework that jointly aligns the cortical and subcortical regions through a unified volume-and-surface-based representation. We do so by jointly learning a volumetric and spherical alignment, producing consistent mappings across cortical and subcortical regions.

I will conclude by discussing open research directions of volumetric shape registration in fields beyond neuroimaging, including computer graphics, medical imaging, and computational biology.

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