Epione team – Master 2 internship proposal

Towards multi-atlas with stationary velocity fields (SVF)-based diffeomorphometry.

Project Description:

The number and ease of acquisition of biomedical images and associated clinical data is ever increasing. We can now study the variability of the anatomy at the scale of a population of subjects and model links with diseases. It thus becomes possible to model the normal and pathological structural variations (phenotype) and to forecast the medical outcome. Building generative models describing the variability of the organ's anatomy at the scale of a population of subjects, and modelling the links with different clinical variables and diseases is the goal of computational anatomy. Pivotal applications include the spatial comparison of healthy and diseased subjects in neuroimaging and atlas to patient registration to map generic knowledge to patient-specific data in medical imaging. Other important applications include cardiac or bone shape modeling.

Many methods compute the mean shape (called template or atlas) and a few variations encoded through tangent PCA or deformation modes. Since shapes and deformations of organs live in non-linear spaces, this program has popularized statistics on manifolds. Despite important successes, anatomical data tend to exhibit an extensive variability than cannot be modeled with such a unimodal Gaussian model, hampering the prediction power. Thus, the field has moved in practice towards multiple atlases.

The goal of our internship is to explore the adaptation of diffeomorphic image registration techniques, and more particularly the stationary velocity fields (SVF) framework, to non-local subspace reduction methodologies such as on the recently proposed barycentric subspace analysis [1] to further extend multi-atlas methods.

In a first step, the work will consist in designing classes to implement the SVF framework and the log-demons algorithm for 3D image registration in the geometric framework of the open source python package geomstats (https://github.com/geomstats/geomstats) [3]. The second step will be to adapt the groupwise registration setup of [2], originally developed for image sequences of the heart, to brain images. Stochastic approximation methods for the choice of reference images and sparsity inducing priors will have to be developed to explore efficiently the configuration space while avoiding an exponential search. This framework will be applied to a subset of heart or brain images and correlation analyses will be performed between the barycentric parameters and the clinical variables (age, disease status, etc) to evaluate the potential of the method.

This subject is planned as an introduction for a continuation into a more ambitious PhD subject with a geometric statistics formulation of the label-fusion for multi-atlas segmentations with potential applications in neuroimaging studies. An interesting research track concerns the geometric interaction between the topological structure of the level sets of the reference images (templates) and the action of the diffeomorphic transformations. Indeed, it has been shown that the standard Procrustes template image construction (that iterate the alignment and the L2 averaging of the aligned images) has a bias that promotes topologically more complex images [4]. Thus, one would like to investigate how to change the metric on images and how to promote or constrain topologically more simple image reconstructions.

- [1] Xavier Pennec. Barycentric Subspace Analysis on Manifolds. Annals of Statistics, 46(6A):2711-2746, July 2018. https://hal.archives-ouvertes.fr/hal-01343881
- [2] Marc-Michel Rohé, Maxime Sermesant, Xavier Pennec. Low-Dimensional Representation of Cardiac Motion Using Barycentric Subspaces: a New Group-Wise Paradigm for Estimation, Analysis, and Reconstruction. Medical Image Analysis, Elsevier, 2018, 45, pp.1-12. ⟨10.1016/j.media.2017.12.008⟩. hal-01677685
- [3] Nina Miolane et al. Geomstats: A Python Package for Riemannian Geometry in Machine Learning. J. of Machine Learning Research (JMLR) 21(223):1−9, 2020. https://www.jmlr.org/papers/v21/19-027.html
- [4] Nina Miolane, Susan Holmes, and Xavier Pennec. Topologically constrained template estimation via Morse-Smale complexes controls its statistical consistency. SIAM Journal on Applied Algebra and Geometry, 2(2):348-375, 2018. https://hal.inria.fr/hal-01655366

Hosting groups:

The Epione team (Inria Sophia Antipolis) is located in the tech Park of Sophia Antipolis and in Nice, in the French Riviera.

Required competences:

Competences in signal processing and statistics are required as well as a god knowledge of mathematics and in particular differential geometry (Master 2 level). Solid programming and IT skills are necessary (Python, bash scripting, version control systems), along with strong communication abilities.

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