PhD position at INRIA Asclepios team Sept 2008 - 2011

Computational anatomy of the brain: from statistics on deformations to robust medical image registration

June 13, 2008

The shape of the brain is very different from one subject to another. At the scale of decimeters, a few tens of cortical folds (sulci) separating the main brain areas can be found consistently in all subjects although they are geometrically very variable. At lower scales, however, many more sulci can be only partially matched across subjects and it is difficult to speak about their homology. Computational anatomy is an emerging discipline at the interface of geometry, statistics and image analysis that aims at analyzing and modeling this type of biological variability at the population scale. The goal in not only to model the mean normal mean anatomy and its normal variations among a population, but also to discover morphological differences between normal and pathological populations, and possibly to detect, model and classify the pathologies from structural abnormalities. Another goal is to correlate these variability information with other structural (e.g. fiber bundles extracted from diffusion tensor images), functional or genetic information. Important applications include the spatial normalization of subjects in neuroscience (mapping all the anatomies into a common reference system). Using these models of normal and pathological variability to better constrain the registration of the generic knowledge of atlases to patient specific images (personalized atlases) also leads to very important applications in many medical image processing applications.

There are nowadays many geometrical and physically-based registration methods that can faithfully deal with intra-patient deformations. However, the absence of physical models relating the anatomy of different subjects leads to rely on statistics to learn the geometrical relationship from many observations. The method is to identify anatomically representative geometric features (points, tensors, curves, surfaces, volume transformations), and to model their statistical distribution. This can be done for instance via a mean shape and covariance structure after a group-wise matching. One side problem is that these features usually belong to curved manifolds rather than to Euclidean spaces. However, there is now a quite well established theory of statistical computing on manifolds [5]. This consistent framework was used for instance to model the brain variability from a dataset of lines on the cerebral cortex in [3]. The dense 3D variability map obtained can be seen as the diagonal elements of the Green's function of the Brain across subjects. This modeling was then extended to capture non-diagonal element by computing significantly correlated regions in the brain [4].

The subject of this PhD is to gather statistics on inter-subject brain variability by performing multiple deformable registrations between a reference image and subject images. We proposed in [Pennec:MFCA06] a consistent mathematical framework called Riemannian elasticity to learn the shape deformation metric from a set of registrations and to use the result as a regularization penalization for new non-rigid registrations. Other ways to compute the statistics include PCA on the initial momentum map with invariant metrics on diffeomorphisms [2] or log-Euclidean methods for computing statistics on diffeomorphisms [1]. This last method is particularly interesting as it allows to develop computationally efficient algorithms to perform non-linear diffeomorphic registration [6]. In particular, the very latest developments now efficiently parametrizes the diffeomorphism by its logarithm [7] which allow integrating some statistics on the deformations in the registration criterion.

Designing and implementing methods to compute statistics on deformations in large databases of brain images and integrating these statistics in the registration criterion to robustify the atlas personalization is the core subject of this PhD. From the methodological point of view, the student will benefit from the important expertise acquired in the Asclepios team over the last years on this subject, but also from the collaboration with other groups pursuing similar objectives. For instance, the INRIA Cooperative Research Initiative BrainVar (`http://www-sop.inria.fr/asclepios/projects/ARCBrainVar/`) is a collaboration with Neurospin (LNAO - CEA and INRIA Futur, Saclay), LENA (Hopital la Pitié-Salpêtrière, Paris), Visages (IRISA, Rennes), LSIS (Marseilles) and CMLA (Cachan) which aims at comparing computational anatomic methods and results on the brain with different sources of information. From the application and computational point of view, this PhD subject will be performed in the framework of the French ANR project NeuroLog (ANR-06-TLOG-024 `http://neurolog.polytech.unice.fr`), a collaboration which aims at developing grid solutions for the processing of large databases of images in neurological disorders. This projects involves in particular the Rainbow team (I3S, Univ. Nice-Sophia Antipolis) for all the grid aspects, and Visages (IRISA, Rennes), Asclepios (INRIA Sophia), the Grenoble Institute for Neurosciences (GIN UMR-S 836), and two teams at the Paris institute for Neurosciences (IFR 49) for the brain image processing aspects.

Requirements

- Master in computer science or applied mathematics
- Good knowledge of signal and image processing
- Knowledge in software engineering on unix and C++ development
- Fluent in English (written and spoken)

Practical Information The PhD student will be hired for a period of 3 years starting between September and December 2008. The PhD will take place in the Asclepios team (`http://www-sop.inria.fr/asclepios/`), at the INRIA Sophia-Antipolis research centre located 20 km from Nice airport.

Contact informatiom Send a curriculum vitae and a motivation letter to

Prof. Xavier Pennec (xavier.pennec@sophia.inria.fr)
Projet-équipe Asclepios, INRIA Sophia-Antipolis
2004 Route des Lucioles, BP93
F-06902 Sophia Antipolis Cedex, France
Tel: 04 92 38 71 59 / 04 92 38 76 64

References

[1] Vincent Arsigny, Olivier Commowick, Xavier Pennec, and Nicholas Ayache. A log-Euclidean framework for statistics on diffeomorphisms. In *Proc. of the 9th International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI'06), Part I*, number 4190 in LNCS, pages 924–931, 2-4 October 2006. PMID: 17354979.

[2] Stanley Durrleman, Xavier Pennec, Alain Trouvé, and Nicholas Ayache. Measuring brain variability via sulcal lines registration: a diffeomorphic approach. In Nicholas Ayache, Sébastien Ourselin, and Anthony Maeder, editors, *Proc. Medical Image Computing and Computer Assisted Intervention (MICCAI)*, volume 4791 of *LNCS*, pages 675–682, Brisbane, Australia, October 2007. Springer. PMID: 18051117.

[3] Pierre Fillard, Vincent Arsigny, Xavier Pennec, Kiralee M. Hayashi, Paul M. Thompson, and Nicholas Ayache. Measuring brain variability by extrapolating sparse tensor fields measured on sulcal lines. *Neuroimage*, 34(2):639–650, January 2007. Also as INRIA Research Report 5887, April 2006. PMID: 17113311.

[4] Pierre Fillard, Xavier Pennec, Paul M. Thompson, and Nicholas Ayache. Evaluating brain anatomical correlations via canonical correlation analysis of sulcal lines. *NeuroImage*, 2008. Accepted for publication.

[5] Xavier Pennec. *Statistical Computing on Manifolds for Computational Anatomy*. Habilitation à diriger des recherches, Université Nice Sophia-Antipolis, December 2006.

[6] Tom Vercauteren, Xavier Pennec, Aymeric Perchant, and Nicholas Ayache. Non-parametric diffeomorphic image registration with the demons algorithm. In Nicholas Ayache, Sébastien Ourselin, and Anthony J. Maeder, editors, *Proc. Medical Image Computing and Computer Assisted Intervention (MICCAI'07)*, volume 4792 of *Lecture Notes in Computer Science*, pages 319–326, Brisbane, Australia, October 2007. Springer-Verlag. PMID: 18044584.

[7] Tom Vercauteren, Xavier Pennec, Aymeric Perchant, and Nicholas Ayache. Symmetric log-domain diffeomorphic registration: A demons-based approach. In *Proc. Medical Image Computing and Computer Assisted Intervention (MICCAI'08)*, Lecture Notes in Computer Science, New York, USA, September 2008. Springer-Verlag.