5.1 Motivation: Time-Resolved Brain Imaging

Better understanding of the interrelationship between the brain’s structural architecture and functional processing is one of the leading questions in today’s integrative neuroscience. Non-invasive imaging techniques have revealed as major contributing tools to this endeavor, which obviously requires the cooperation of space and time-resolved experimental evidences. Electromagnetic brain mapping using magneto- and electro-encephalography (M/EEG) source estimation is so far the imaging method with the best trade-off between spatial and temporal resolution (\(\sim 1\text{ cm}\) and \(< 1\text{ ms}\) respectively, [4,5]). Combined with individual anatomical information from Magnetic Resonance Imaging (MRI) and statistical inference techniques [35], M/EEG source estimation has now reached considerable maturity and may indeed be considered as a true functional brain imaging technique.

With or without considering the estimation of M/EEG generators as a priority, the analysis of M/EEG data is classically motivated by the detection of salient features in the time course of surface measures either/both at the sensor or/and cortical levels. These features of interest may be extracted from waveform peaks and/or their related time latencies, band-specific oscillatory patterns surging from a time-frequency decomposition of the data or regional activation blobs at the cortical level.

By nature, the extraction of such features usually results from an extremely reductive – though pragmatic – point of view on the spatio-temporal dynamics of brain responses. It is pragmatic because it responds to a need for the reduction in the information mass from the original data. It is reductive...
though because most studies report on either/both the localization or/and the dynamical properties of brain events as defined according to the investigator, hence with an uncontrolled level of subjectivity.

This suggests there is a need for innovative methodological solutions that would help detect salient events in the course of brain responses in a given experimental context.

The major issue that must be faced concerns the very large amount of data produced by M/EEG acquisition. At anytime instant, brain activity unfolds at multiple cortical areas. The unique temporal resolution of M/EEG yields a large set of typically 1,000 functional brain images at every second while brain activation unfolds at multiple cortical areas on a complex shape surface object of about 2,500 cm$^2$.

In this chapter, we suggest to develop new indices related to the appraisal of brain activations in space and time, in direct connection with their anatomical substrate. These indicators are built from the empirical observation of scalp potentials and magnetic fields, but also of distributed brain currents that are literally perceived as flowing onto the underlying manifold. Therefore, we have adapted the computation of the optical flow – which is well-known to computer scientists when computed on 2D picture series – to arbitrary surfaces.

Though the motivations stem from neuroscience, we might think of multiple other application fields to this techniques such as, e.g. fluid streams onto surface supports but also realistic models of biological vision from the retina.

It is also interesting to note that this tool may prove as useful in the challenge of relating the experimental evidence of brain activation at the macroscopic/global scale with computational models from system dynamics (see [34] for a wide review and more specifically [27], concerning the issue of wave propagations along the cortical surface).

5.2 Velocity Fields and Transport on Riemannian Surfaces

In a large number of applications, spatiotemporal properties of image sequences may be represented and explored using vector fields. The information conveyed by such vectorial representation provides the support for the temporal analysis of evolutionary dynamic patterns and – possibly – their spatial segmentation. Originally, optical flow techniques were developed in computer vision to elucidate the apparent motion of rigid objects in visual scenes via the estimation of a dense vector field. In that respect, Horn and Schunk were pioneers in suggesting a regularized method to this problem [23] (see, e.g. [8] for an updated review of multiple approaches) and further quantitative improvements (see [6], [30] for other specific reviews). It further came out that optical flow usage could be extended to the characterization of complex dynamical