PhD Project Proposal:

Structural and Functional Visualization of Brain Connectivity

The study of brain connectivity is one of the fundamental ways to investigate the complex functions of the (human) brain. For this purpose, neuroanatomists capture and investigate two different types of connectivity: anatomical connectivity arising from diffusion-weighted MRI measurements and functional connectivity based on fMRI scans. Both types of data have advantages and disadvantages, but ultimately it is essential to study them in concert.

The research in this PhD project will employ and combine approaches from two sub-fields of visualization: the visualization of spatial relationships (SciVis, for anatomical connectivity) and the visualization of abstract data (InfoVis, for functional connectivity data). The goal is to be able to start the interactive investigation with either type of data, being able to interactively and freely switch between the different representations as it is needed for the data exploration. The ultimate vision is two-fold: The first and foremost aspect is to get to a more in-depth understanding on how to support interactive data exploration using various new and state-of-the-art visualization techniques in the neurosciences. The second aspect is that to more generally push the boundaries of multimodal visualization to be able to generalize the findings of this research to other fields that work on a daily basis with data that has both spatial and abstract characteristics.

For this purpose the project extends past results in the visualization of dense line data as well as the visualization of weighted graphs. For the first aspect of anatomical connectivity, the project will use methods from illustrative visualization to deal with the dense fibertract datasets that are generated from diffusion-weighted MRI. This aspect of the visualization will provide an important visual reference and landmark for the exploration of functional connectivity, for which the project will rely on the visualization of weighted graphs. A general challenge in this context is the question on how to create a visualization that combines both data types, either in separate views or in a combined view. Separate linked views are common in abstract data visualization and we will thus explore their application for our application. A view that integrates both could combine fibertracts inside the brain for anatomical connectivity with a bundled view of functional links on its outside. This approach has the potential benefit of not requiring a mental integration of separate points of reference. On the other hand, this approach may lead to a cluttered and overloaded depiction. The project will therefore explore new ways of controlling the abstraction in the data depiction to deal with this issue to be able to show the realistic large and complex datasets. This work will thus also require research to understand how to apply illustrative visualization to abstract data.

Such visualizations of the fibertracts in a more or less realistic way is convenient for the neuroscientist, but we have to consider other complementary linked views. These views often do not match the realistic physical appearance of fibertracts but instead focus on the task at hand the neuroscientist wants to perform with the data. So other representations than graphs will be explored as part of this project such as scatter plots or space-filling or pixel-based designs enabling to provide a mapping of the information space more efficient to solve a specific visual analytic task. Machine learrning techniques such as generative graphs will be used to automatically extract summaries of the anatomical and functional connectivity data. These geometrical and topological summaries will be used as a backbone structure for the visualization of the information space to be used for visual analysis tasks.

Moreover, an integral aspect of our approach is to combine the visualization techniques in an interactive exploration tool that supports analists in adjusting their exploration strategy as needed. An integral part of the neuroanatomists' data exploration is the comparison of different datasets, either derived from different people or captured at different points in time. Therefore, the comparison of different datasets and the temporal exploration will be an essential aspect of the project. To be successful in this project, the PhD student will work closely with domain experts in the neurosciences from the Université Pierre et Marie Curie, both to develop the integrated interactive visualization techniques using a participatory design approach as well as to evaluate the new techniques in controlled experiements.

By closely working with the domain experts, the PhD student will work toward an interactive tool for neuroanatomical data exploration that integrates the new visualization techniques. The goal for this tool is that it can be used in a realistic context for the everyday analysis tasks of the neuroanatomists and that it will be provided to the public as open-source software. Beyond this implementation, the project will result in a deeper understanding of how to combine spatially explicit data with connected abstract data aspects to benefit visualization in the sciences in general.

The PhD research will be conducted under the supervision of Tobias Isenberg and within the AVIZ research team at INRIA Saclay—Île-de-France which concentrates on the visualization of complex data. AVIZ is one of the most respected research labs in information visualization and visual analytics worldwide. The PhD student will closely collaborate, in particular, with Michaël Aupetit from the Laboratoire Analyse de Données et Intelligence des Systèmes at CEA whose expertise in machine learning will be essential for the work. In addition, we will work with domain experts in the neurosciences from the Université Pierre et Marie Curie.

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