Visualization to Facilitate Structured Exploration of Published Findings in Rat Brain Connectivity

Hua Guo* Brown University
Steven R. Gomez† Brown University
Mark J. Schnitzer‡ Stanford University
David H. Laidlaw§ Brown University

Abstract

We present the design, use cases, and user feedback for an online visual analysis tool for integrating brain-network findings. We report needs and challenges in studying brain connectivity as identified in close collaboration with domain experts and describe how they inform the design of a web-based tool for visualizing, annotating, and analyzing findings on rat-brain connectivity. By representing both the hierarchical and connectivity structure of the brain, the tool augments the original information space through basic inference and facilitates structured exploration of publications on brain connectivity. We finally report use cases and open challenges in this domain as derived from user feedback. We found anecdotal support that neuroscientists using a multi-scale visual analysis tool can find useful connection information more quickly or discover more information than by using traditional searches like PubMed queries.

Index Terms: H.5.2 [Information interfaces and presentation]: User Interfaces;

1 Introduction

An important step in studying brain connectivity is generating hypotheses about how different brain regions are connected. Our interviews with neuroscientists suggest that reasoning with existing knowledge about connectivity is challenging due to the large amount of information available, the complexity of analysis questions, and the heterogeneity in anatomical levels and techniques used in connectivity experiments. As of 2010, PubMed indexes over 7,000 publications on topics related to brain connectivity [6]. The reported experiments use a variety of techniques that measure different aspects of brain connectivity and have different types of errors and uncertainty. Experiments can also be performed at different anatomical levels, ranging from neuron projections to co-activations among major brain regions. It is important to distinguish among and also bridge findings derived under these different conditions, which is difficult with simple textual queries over the publications.

We address the challenges above with a study of visualization tools for brain connectivity researchers. The contributions of the work are: 1) an analysis of the needs and challenges in brain connectivity analysis; 2) the design of BraiNet, an online visual analysis tool for exploring and retrieving publications on rat brain connectivity; 3) case studies demonstrating how users can benefit from incorporating visualization into their analysis.

2 Related Work

Our work builds upon existing work in hierarchical network visualization techniques. A brain connectivity dataset can be abstracted as a hierarchical network which contains two types of edges: inclusion edges that represent parent-child relationships and adjacency edges that represent neighborhood relationships. Some existing works have added edges representing neighborhood relationships directly on top of a hierarchical visualization method like TreeMap [3] to visualize hierarchical networks (e.g. [4]). This approach, however, sometimes can lead to visual cluttering, especially if the underlying hierarchical visualization technique uses a space-filling algorithm. The primary visualization technique used in this work builds upon TreeNetViz [5], which is designed to visualize hierarchical networks while reducing visual cluttering. Our design, however, differs from TreeNetViz to accommodate properties unique to brain connectivity data as described in Sec. 3.

3 Online Tool for Rat Brain Connectivity Analysis

We started by interviewing neuroscience experts from two research labs and conducting a survey at two universities in order to identify core analysis questions, challenges, and needs in the study of brain connectivity. We then developed a web-based tool called BraiNet that organizes and visualizes existing connectivity information for rat brain. BraiNet is written in Javascript using the D3 library [1] and provides two different datasets. The first dataset being visualized is based on connectivity data from the Brain Architecture Management System (BAMS) [2], whose dataset was generated by curation of hundreds of PubMed publications on neuron projections in rat brains. The second dataset also uses the BAMS ontology but contains uncurated PubMed articles on rat brain connectivity that are mined by automating search queries using E-Utilities provided by PubMed. Users can also extend the datasets by adding brain regions, connections, links to publications, and annotations.

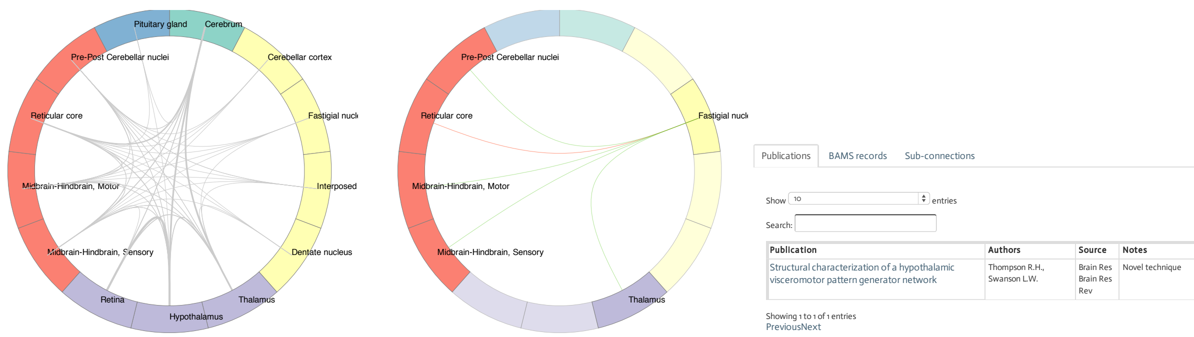
BraiNet provides an exploration view, an anatomy view, a document view, and an accompanying control interface. Below, we summarize observations about the problem space based on formative evaluations with neuroscientists and describe how the design of the BraiNet prototype addresses each.

Neuroscientists explore brain connectivity on multiple scales. We chose to build the exploration view (Fig. 1a) on top of TreeNetViz to visually encode the brain's anatomical hierarchy as well as its connectivity. Arcs around the circumference represent brain regions and links represent connectivity edges. Only the top-level brain regions are shown initially to reduce visual clutter. Users can expand a region into structures that are one level deeper in the hierarchy. Unlike TreeNetViz, the arcs are colored based on their coarse anatomical locations instead of depths to help the user maintain an anatomy-based mental map, and the underlying data structure is extended to handle cross-scale edges.

Displaying the original sources of connectivity information is crucial. By clicking the visual link that represents each connection, the tool displays a list of publications associated with the selected connection in the document view.

Neuroscientists are often interested in local connectivity. The user can highlight a brain region to examine its connectivity. Connections not associated with that brain part will be hidden and irrelevant brain parts will be dimmed, as shown in Fig. 1b. Connections associated with the highlighted region are colored to show directionality.

*e-mail: huag@cs.brown.edu
†e-mail: steveg@cs.brown.edu
‡e-mail:mschnitzer@gmail.com
§e-mail:dhl@cs.brown.edu



(a) The user clicked and expanded the cerebellum and midbrain-hindbrain.

(b) The user mouses over the fastigial nucleus to show the associated connections.

(c) The publication view showing the list of publications associated with the link dentate nucleus - thalamus.

Figure 1: Snapshots of selected stages of exploration in the case study.

Visualizing brain anatomy helps neuroscientists understand it. BraiNet provides an anatomy view built using APIs provided by Allen Brain Institute. The anatomy view is linked to the exploration view, and selecting a brain region in one view will trigger updates in the other to show and highlight the region's location.

There are many variations in naming and organizing brain regions. The tool ameliorates the problem by letting users define new regions or rename existing regions in the BAMS ontology using the tool's interface.

Tracing indirect connections should be easy. Users can search for indirect connections, which will trigger updates in the exploration view so that only connections involved in the path from source to target are visible and irrelevant nodes are dimmed. The user can mouse over a single node or a single connection to highlight the corresponding paths.

Neuroscientists are often interested in how two brain regions are connected, not merely whether they are connected. Given a chosen connection attribute, BraiNet automatically maps the attribute values to a discrete, sequential color map and colors the links accordingly. Attributes can also be used to filter the connections being drawn. The width of a link reflects the number of publications associated with that connection.

4 Case Study: Cerebellum and Motor Control

We introduced BraiNet to the neuroscientists we interviewed and observed how they used it. We now describe one scenario observed during these sessions. The neuroscientist in this scenario studies the role of the cerebellum in motor behaviors. He wants to use BraiNet to analyze existing results to sort out which cerebellum nuclei project to the motor cortex directly and which project to it indirectly through the thalamus. Using BraiNet, the user was able to see a complete picture of the connectivity among the three regions of interest, both at the region level and at the nuclei level. Snapshots of selected stages of the exploration are shown in Fig.1. In addition to finding BraiNet easy to use, User A was also surprised to discover a connection he had missed when doing a literature search using PubMed. The newly discovered connection was a projection from the interposed nucleus inside the cerebellum to the geniculate complex, a structure within the thalamus. BraiNet finds and displays this connection by leveraging the hierarchical structure of the brain. In contrast, traditional search tools without hierarchy-based inference missed this connection. Anecdotal comments from the user also suggest that using BraiNet to accomplish this task is more effective compared to querying the BAMS dataset directly, since the latter involves performing multiple searches to enumerate all the nuclei inside the cerebellum while also specifying brain parts on multiple levels to provide more context.

5 Discussion

User feedback suggests that there are many other analytical tasks and needs (e.g. comparing brain-network activities under different behavioral conditions or identifying connections that have no related publications) in brain connectivity analysis that go beyond those outlined in this work. It is unlikely that the radial visualization used in this work will be a good fit for all tasks, and it would be interesting to perform a formal evaluation of BraiNet to assess the effectiveness of the visualization given different tasks. Taking this one step further, the diverse analytical needs and hierarchical nature of the data in brain connectivity analysis could provide us with opportunities for evaluating and comparing more hierarchical network visualization techniques with analytical tasks derived from real-world tasks.

6 Conclusion

We identified needs and requirements for a visual analysis tool that supports hypothesis formation and the exploration of published findings in brain connectivity research. We designed an online visual analysis prototype that addresses basic needs in brain connectivity analysis. We illustrated one use scenario for BraiNet observed during a session with neuroscientists, and found anecdotal support that BraiNet helps users find information more quickly and discover richer information than with existing search tools. Finally, we discussed opportunities for evaluating more hierarchical network visualization techniques using analytical tasks derived from brain connectivity analysis.

Acknowledgements

We would like to thank members of the Schnitzer lab, members of the Badre lab, and Steven Sloman for their feedback on the tool.

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