NeuroCave VR

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Introduction

A human brain has one hundred billion neurons and some seven hundred trillion synaptic connections. A connectome is the complete map of the neural connections in a brain. It is sometimes referred to as a "wiring diagram" of the molecular connections between neurons, trading on the analogy of a brain to an electronic device, where axons and dendrites are wires and neuron bodies are components. Several studies have linked many neurological and mental disorders like autism and dyslexia to the disruption of brain connectivity. These studies needs to be investigated in detail to further understand the functioning of a brain but there is a lack of tools to do so. Comparing the connections of different individuals or with an average will tell us the underlying working in terms of regions and their pathways.

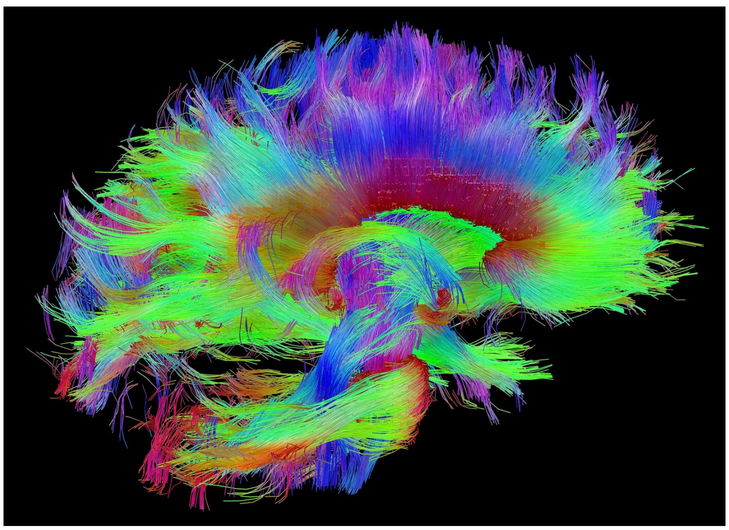

Figure 1: Connectome visualization showing the connections between neurons

Visualization tools are need for simplifying the analysis of the connections. As shown in figure 1, the connections can get pretty complicated easily even if we are visualizing a small part of the connectome. A smarter way of dealing the high density data is needed with a complimenting visualization for exploration and for comparison. Several visualization tools are available for connectome visualization but they either lack data simplification or don't support the functionality scientists for comparing different dataset. In summary, the goal of this project will be as following:

- Visualize multiple connectome datasets in different coordinate systems in VR
- Identify regions responsible for specific cognitive functions and study their interactions with other regions.
- Compare individual networks to the mean or group average connectome, or compare differences between two group average connectomes.

Related Works

Some work has been done for representing neurocave. A popular 2D technique to highlight relevant brain connectivity patterns is the connectogram, and an example is shown in Figure 2. In a connectogram, the names of each brain region are presented along the perimeter of a circle. While the main goal of the connectogram is to more effectively represent densely connected networks. In this work, 2D representation does not have much of spatial information, the connections are confusing if users want to see the connections between the nodes, and it will be hard to compare multiple connectomes in this form of representation.

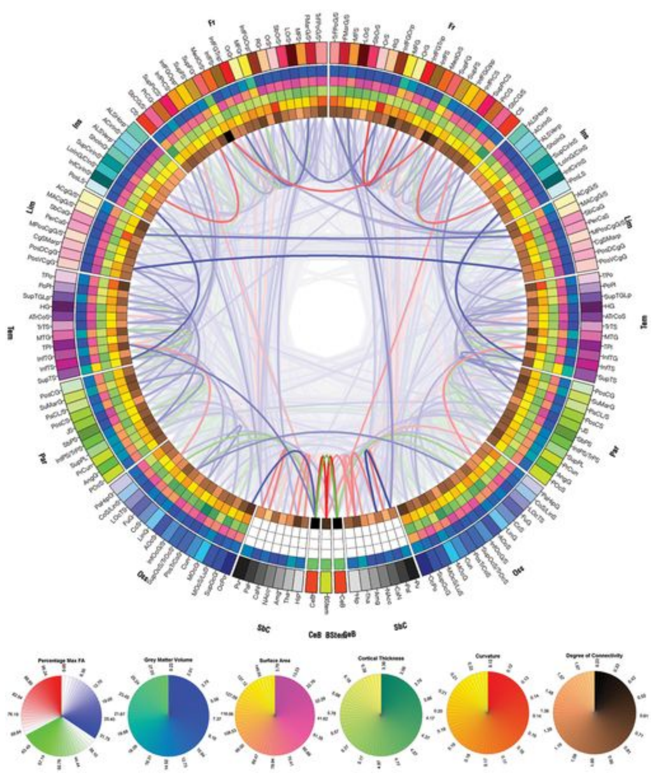

Figure 2: An example of a 2D connectgram

Another related work done is visual connectome, which is shown in Figure 3. In this work, the data is show in 3D version with the connections between notes, and also, the information about the notes is shown on the left upper conner. However, visual connectome cannot show different regions of connectome, plus it does not support comparison of different connectome and also there is visual clutter due to edge crossing.

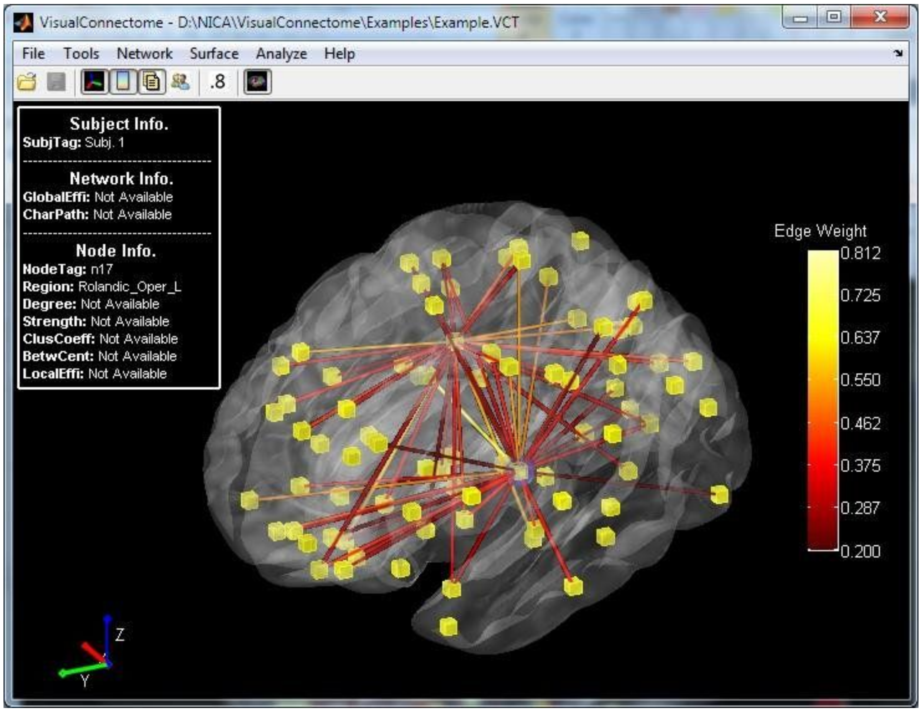

Figure 3: Visual Connectome

There are many tools for visualizing connectome datasets, but none of them provides a visualization that can involve comparison between different datasets. NeuroCave VR will enable researchers and neuroscientists to do comparative analyses in a single view.

NeuroCave Web Version

Previously, NeuroCave team has developed a web-based application which used Three.js. The default view is two side by side rendering views. Each view enables the interactive visualization of a connectome of a node-link diagram. In this version as shown in Figure 4, the features includes: A. shows a high functional connectome; B. Shows the same connectome from a different orientation; C. Shows the color atlas, users can choose specific brain regions; D. Change opacity; E. Choose edge bundling on and off; F. Set the threshold values to determine which edges to display; G. Highlight a node and show the connections. However, this version has some drawbacks: users cannot import their own data to visualize, and it doesn’t support multiple connectomes in a single view. Multiple connectomes can be best represented in 3D space of virtual reality since users will have a 360 degree view. And a better user interface in VR will also allow users to have best interaction with the data. So in the NeuroCave VR version to representing connectome, the two features will be added on the existed features in the NeuroCave Web version.

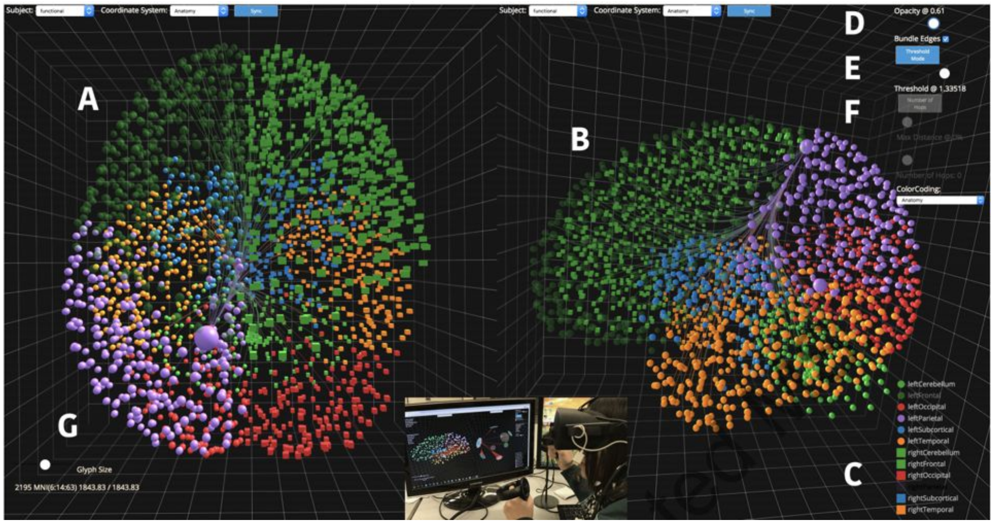

Figure 4: NeuroCave WebGL

Dataset

Dataset consist of high-resolution fMRI scan of 2514 regions of interest and their connections. Individual connectome data and data from a specify class such as people with a particular disorder are collected. The class data is combined to get the group average connectome which is useful in finding the similarities or dissimilarities with the individual connectomes. The dataset consist of anatomical or structural information about each neurons, along with functional information about the connections. The functional information is obtained using a preprocessing step where the high-dimensional connection data is brought to a lower dimensional space using a dimension reduction technique. Different dimension reduction techniques are used here since each has their own advantages and provide us with different patterns. In dataset we have Isomaps, Tsne and MDS for the connections. We also have data on the connection strength for different cognitive functions. These connections are a big network matrix with scalar values indicating the strength.

Tools

For this project, there is a need for a hardware component and a software component. The hardware component is the VR headset and its corresponding controller. We want to support this project in all mainstream VR headsets including Oculus Go, Gear VR, Windows Mixed Reality Headset and HTC Vive. Each headset has their own development environment, camera configuration, and control settings. The challenge here is making the VR app as uniform as possible across the headsets. Additionally, the PI is interested in loading custom data into the VR app which brings up a new challenge of loading data into standalone headsets without making changes to the project. Considering all the challenges involved in the project, we decided to work with Oculus Go and then move on to other headsets in the future. Oculus go has several advantages with respect to the project. It is a standalone headset and doesn't need a computer to power the headset. It also uses the same development kit as the Gear VR, which makes it easy for the PI to test the progress.

For the software side, we decided to go with Unity engine. The previous version of neurocave was built in WebGL which had an issue with data loading and VR in general. Unity is optimized for real-time graphics and it can easily load 10+ connectome data at a time with frame rate issue. Unity also supports state of the art lighting and shading model which is essential to make the connectome data beautiful. All the mainstream headsets provide Unity plugins and the underlying engine will help us use the same data framework with different headset configurations.

Proposed work

Virtual reality visualization will allow users to have more space to view massive data, which make it easier to show multiple connectomes at once and connections between each nodes will be best represented. The proposed work in Unity will mainly have the following:

- The main features we are proposing in the NeuroCave VR version will firstly import all the features to VR representation. The tools we will use is Unity, which will be totally different with Three.js. So we will need to develop different algorithm to implement edge bundling.
- Other than that, we will load multiple connectomes and allow users to drag different connectomes and compare them side by side.
- We will setup interface for users to upload their own data.
- Show changes in functional connectivity over time
- 3D Lighting and shading for better visual inspection
- Make connectome data beautiful

Interview with the PI

- **If we have a unity version of neurocave, what are the interactions you would like to have? Ie: what kind of comparison would you like to have?**
    - PI is interested in seeing the connectome dataset in different representations. The representations have both structural and functional components. Some representation are in reduced dimensional space which shows interesting patterns
    - PI wants to visualize the temporal data of a single connectome to study how the connection varies over time. This can be shown as an animation with changing connection strength
    - When comparing different connectomes, PI would like to highlight the same region in all connectomes when a small region in connectome is selected by the user.

- **Who are the users?**
    - Primary users for this tool are neuroscientists and researchers studying brain connectivity.

- **Do you want to include all three: mds, isomap, tsne? Dimension reduction on the fly?**
    - Isomap and tsne simplify the connection data by bringing it down to a lower dimension. In future PI is interested in doing this step in real-time.

- **Have you used or tried any other connectome visualization tool? What did you like and what did you dislike?**
  - PI and his colleagues have tried several visualizations dealing with connectome data but none of them provide tools to see the data in different representation or lets you compare two different connectomes.

- **What were the drawbacks of neurocave web version?**
  - Neurocave lack support for loading in custom data and support for comparing different connectome data. The VR feature relies on WebVR and is buggy which makes the VR experience unsatisfactory.

- **Why do you think VR is important in visualizing connectome?**
  - According to the PI, the connection from on to another (centrality) is best represented in VR. This is important to see the strength of edge connections corresponding to various cognitive tasks.
  - PI is very interested in comparing multiple connectomes, which is hard to do in a traditional desktop 3D application because of visual clutters. In VR, we can take advantage of the endless 3D space to show a vast important of information with crowding the region.
  - Since we are dealing with 2000+ regions of interest and their connections, there's a lot of information to show as labels and properties. This will be easier to show in a VR space.

NeuroCaveVR Features:

NeuroCave VR allows users to upload multiple connectomes. Our system is capable of showing eight connectomes simultaneously at 60 frames per second. The connectomes are dynamically arranged in a circle layout as shown in Figure 5. View from the VR camera is shown in Figure 6.

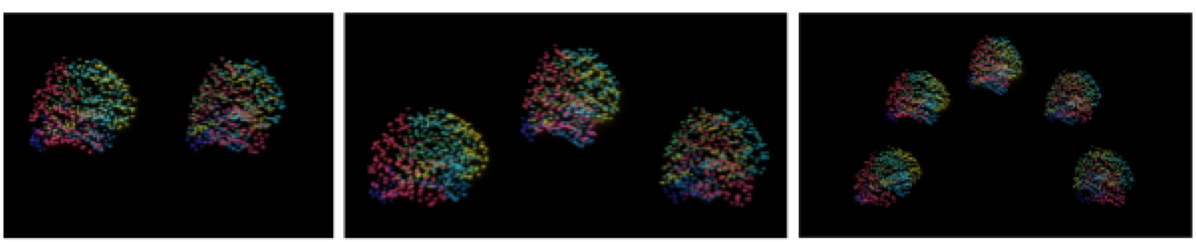

Figure 5: Dynamic Connectomes Layout

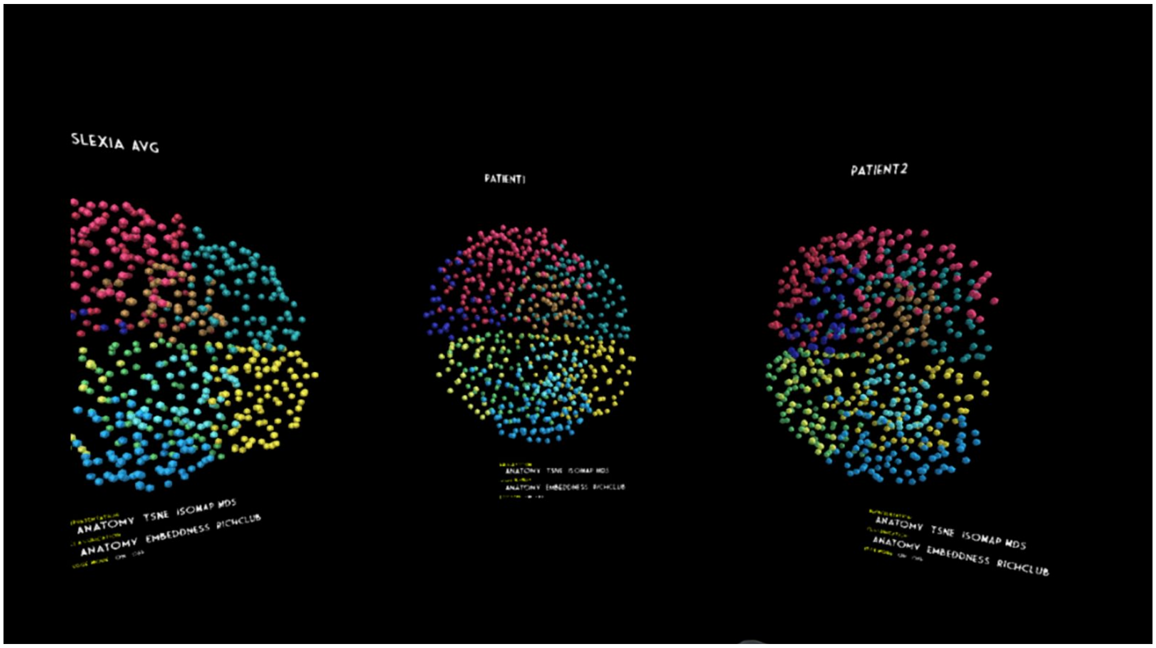

Figure 6: Connectomes around Camera

Representation and Classification

Each connectome is identified by a name on the top and comes with its own menu. The menu includes different representations, classifications, as well as an edge mode option. User can choose Anatomy, Tsne, Mds, and Isomap from the representation panel and Anatomy, Embeddedness, and Richclub from the classification panel as shown in Figure 7.

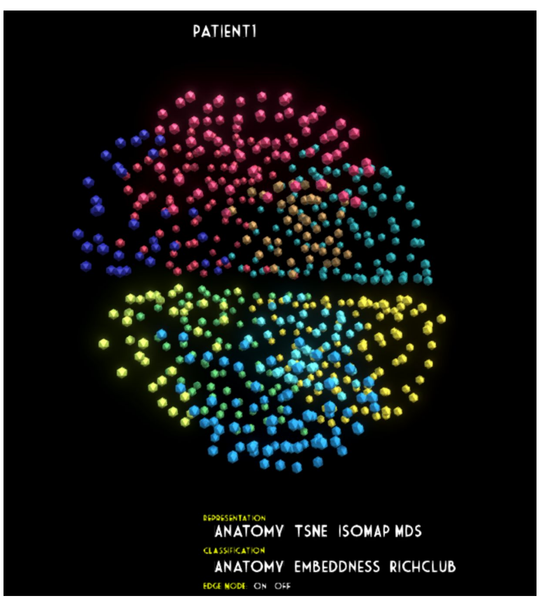

Figure 7: Single Connectome

Comparison

User can grab the interested connectomes using the controller and move it to an empty region in the VR space. Figure 8 shows the connectomes of two patients, one with tsne representation classified using anatomy and the other one is representing using mds with embedeness as the classification. With the edge mode off, users can drag, move around, and scale the connectome.

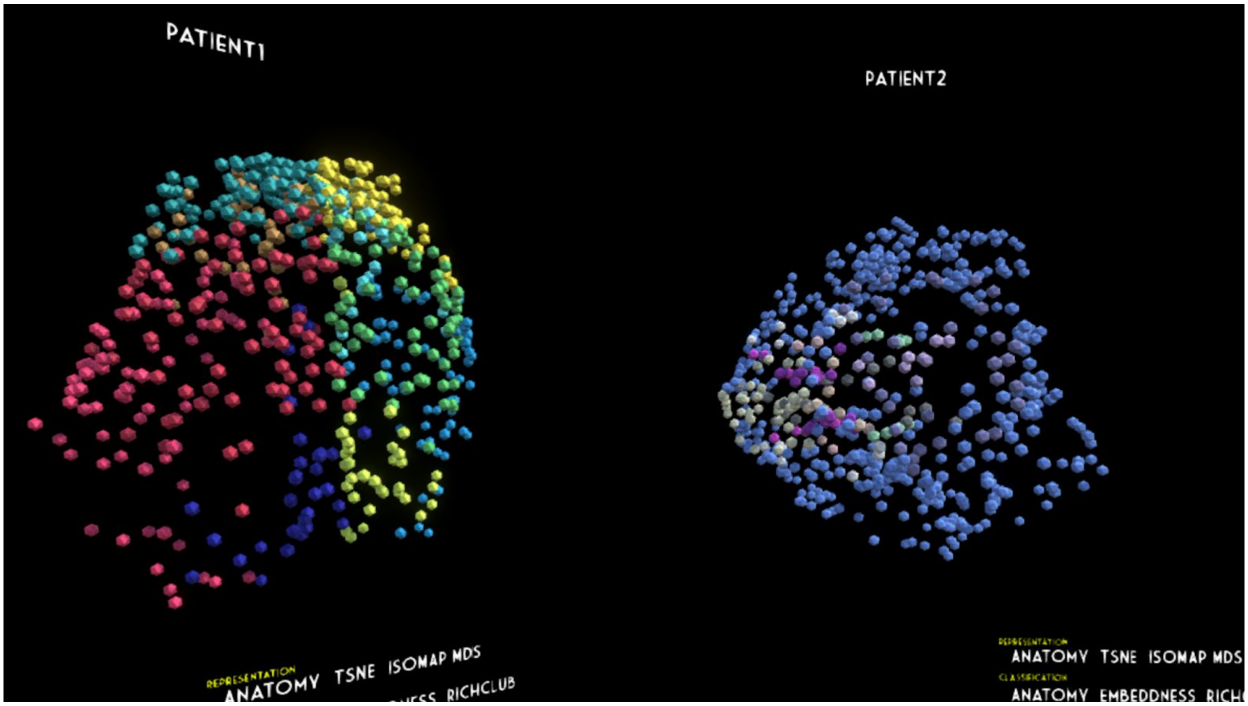

Figure 8: Comparing multiple connectomes

Edge Mode

Edge mode shows the connections of a node to other nodes. With edge mode selected, users can click on a node and visualize the edge connections from that node to all other nodes. The connections between the nodes are associated with a threshold parameter, so users can set a min and max threshold and the system filters the edge accordingly. To turn off the edge connection, simply click the nodes again and the edges disappears. This is shown in Figure 9.

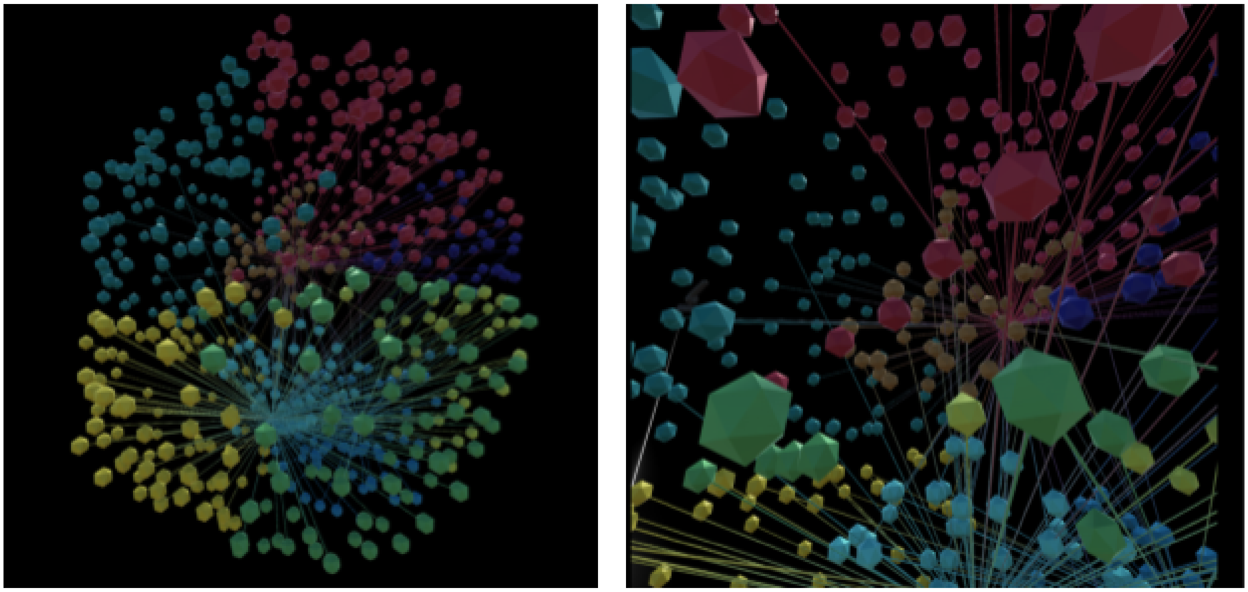

Figure 9: Edges