ConnectoMotion

Connectomic Graph Navigation and Exploration

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ABSTRACT
The goal of this work is to enable a meaningful representation and navigation of the human brain connectome by using hand gestures in midair, allowing the user to explore it. To accomplish this, some systems and methods were analyzed in order to discuss the best approach to use in the developing of the system. The solution resorted to Leap Motion in order to capture the hand gesture. With the elaboration of a set of operations, it was possible to navigate and interact with the graph. To choose the most appropriated gestures for the interaction, it was made a survey with users. To validate the interaction with this interface users test were conducted. During the tests the device proved to be easy and intuitive to interact with the majority of users, this fact was noticed that some users were able to perform tasks quickly and with few errors, since the users had no prior training with Leap Motion, thus achieving the desired goals of the study.

Author Keywords
Human Brain Connectome; Midair gestures; Hand gestures; Leap Motion; Graph visualization; Graph navigation.

INTRODUCTION
Nowadays, people have to work with large datasets in many different fields of work or study. Datasets are very large collections of related, discrete items of data that can be accessed individually or in combination or managed as a whole entity. To be able to work and understand these vast collections of data we must be able to represent and explore them [11].

An effective method for representing large amounts of data is through the use of networks, also known as graph structures [11]. This kind of structures can easily represent relations between objects, by representing objects as nodes and associations as edges. However, the complexity of these networks is huge and can imply a lot of cluttering. One way to reduce this effect is to use a three-dimensional space environment.

With this approach, we answer the question of how to represent these datasets, but the question of how to explore it remains to be answered. A possible approach would be the exploration using a mouse, but recent studies showed that the use of natural hand gestures to manipulate tridimensional environments proved to be a better way to explore in such environments compared to the exploration through the mouse [6], since it is a more direct physical analog to everyday experience.

The goal of this work is to enable a meaningful representation and navigation of the human brain connectome by using hand gestures, allowing the user to explore it and find relevant information.

This study is a collaboration between Instituto Superior Técnico (IST) and Instituto de Biofísica e Engenharia Biomédica (IBEB) in order to try to solve the problem of visualizing and navigating a large dataset that is the human brain connectome through the use of hand gestures because the researchers in the field of neuroscience feels the need for new ways to explore this data.

RELATED WORK
There has been some investigation respect to methods for representing and navigating of information in graphs.

Representation
The ones that focus on representing graphs were: FORG3D [9], H3 [10], Connectome Viewer Toolkit [5] and GEOMI [1]. All of them have the advantage of representing large graphs, however the H3 also has the advantage of having a highlighted node and the visualization changes in function of this node, the Connectome Viewer Toolkit has the advantage of representing the nodes at a fixed position and the GEOMI has the advantage of representing graphs with hierarchical structures.

Navigation
The ones that focus on navigations were: WilmaScope [2], GEOMI [1], XIM [3] and NaturalMotion [4]. The WilmaScope has the advantage of using a widely used device that is the mouse and also has a set of operations that are easy to learn and use. The XIM and NaturalMotion has the advantage of using hand gestures to interact with the graph, also the NaturalMotion has an easy setup, but XIM needs a glove to do the tracking of gestures which makes the interaction not so natural.

It is thus relevant tried to take advantages of the strong points of these systems. One key feature that was incorporate is the use of spatial field to represent the connectome, as mentioned before in neuroscience it is
important to represent each element of the brain in their respective position.
Another feature used in the system was the use of the Leap Motion device in order to capture gestures and movements of the user, this kind of manipulation as shown to be a useful way to users interact with tridimensional representations.

CONNECTOMOTION
The solution consists in the development of a system that is capable of capturing hand gestures to navigate a meaningful representation of the human brain connectome. Through the analysis of gestures, it is intended for the user to be enabled to execute different operations in order to explore data in a way that is similar to the way people manipulate objects in the real world.

Dataset
The object of study that this work will focus on is the Human Brain Connectome. The Connectome was created to offer a structural description of the Human Brain, which is composed by approximately $10^{10}$ neurons and $10^{13}$ connections just in the cortex. Several proposals were presented to make this representation and three approaches to the visualization of this information emerged: Microscale, Macroscale and Mesoscale [13].

Microscale: at this scale, the human brain connectome is represented at the level of single neurons and synapses. This kind of detail leads to visualizations with a large degree of complexity and it can be unnecessary or irrelevant.

Macroscale: this scale is concerned with the representation of brain regions and pathways. One advantage comparing with the microscale is that the neurons are well defined elements while there is no universal consensus on the exact delimitation of the regions, which correspond to cluster of neurons. Representing only the regions of the brain implies removing a lot of complexity to the visualization, diminishing the cluttering of the graph. At this level of representation, it is only necessary to represent all the connections between two regions as a single link (edge).

Mesoscale: this scale is somewhere between the microscale and macroscale. Instead of representing large sections of neurons like the macro scale it represents anatomically or functionally distinct populations of neurons. The brain regions in this scale will be a set of small population of neurons. This scale will be less complex compared to the microscale, but more informative than the macroscale.

The dataset used for this work was the Automated Anatomical Labeling (AAL) [12] that is a representation in Macroscale. The AAL is a digital human brain atlas with a labeled volume

Capturing Hand Gestures
To detect and capture hand gestures and movements we used Leap Motion [7]. It is a system that combines software and hardware to track the movement of hands and fingers with very low latency, converting it into 3D input.

A study using Leap Motion was made in order to determine how accurate the system was to recognize gestures [8] and they concluded that this device is suitable to use in gesture interacted systems.

Solution Architecture
Figure 1 presents the architecture of the solution that was developed in this project.

Unity was the platform used to analyze the user gestures provided by Leap Motion device, in order to interact with the connectome. The dataset of the human brain connectome was stored in a text file, that was supplied to Unity in order to be parsed and obtained the matrix that represent the graph of the connectome. In this platform, with the Leap Motion asset, was made the interpretation of the user gestures in order to do the gestures identification and create the manipulation of the connectome.

Survey
In order to decide how interaction/navigation was to be performed with the interface, it was necessary to carry out a questionnaire with users. Thus, a survey was made of possible gestures for the interaction of the user with the interface. Six gestures were selected, two for each interaction method, with the aim of selecting only one for its realization.

Rotation:
- Gesture of Pinch with both hands;
- Gesture of Swipe with one hand.

Zoom:
- Gesture of Pinch with both hands;
• Gesture of Grab with one hand;  
  Pan:  
• Gesture of Pointing with one hand;  
• Gesture of Pinch with both hands;  

Procedure  
The participants for the survey were recruited through standard procedures, which included ads on social networks, by direct contact and participant were also asked to refer other people who were interested in participating in the survey. The users always performed the survey in my presence, so it can clarify doubts about how the proposed gestures for each method are performed. In this survey, I went to meet the users and the questionnaire was answered in a comfortable space chosen by the user. Before performing the survey, the user was shown Leap Motion device operating in the Leap Motion Visualizer application and the user was told to interact with the device in order to understand how it worked and also to understand the type of sensitivity of the device. In the beginning of the survey, it was explained to the users the purpose of this study. Each participant was asked to sign consent form in order to allow the collection of their personal information.

Survey Results  
Analyzing the scores obtained for each method we can conclude:  
• For the method Rotation users preferred the Pinch gesture with both hands, as users considered Pinch to be able to rotate the objects more accurately while Swipe, although it seemed more intuitive to execute, did not produce the same level of precision.  
• For the Zoom method users preferred the Pinch gesture with both hands, they think that this gesture is the best to perform this action since it is a gesture simpler and easier to manipulate and associated with the gesture often used in touch devices.  
• Regarding the method Pan, users preferred the Fist gesture because they associate this gesture with the action of grabbing and dragging an object and by the ease of execution of the gesture. However, the users had some indecision in the choice of this gesture.  

Interface  
The objective of this study was to create an application that allowed the interaction through gestures captured by Leap Motion and interpreted by the application, as such was used the Unity platform to develop this interface. With Unity, it was possible to render the connectome has a 3D graph and by using Leap Motion combined with the gestures obtained from the survey it was possible to interact with the connectome. The interface offered the following interaction methods:  
• Rotation: consists of performing a pinch on both hands. If the hands move in depth, each hand in opposite directions, the object is rotated on the y-axis. If the hands move in height, each in opposite directions, the object is rotated on the z-axis;  
• Zoom: consists of a Pinch (join the tips of the index and the thumb) in both hands. If the hands move away from each other along the x-axis, a Zoom In is produced, otherwise, the hands will zoom in on each other;  
• Pan: consists of closing the hand (making a fist) and depending on whether the hand moves horizontally or vertically the object moves in the same way;  
• Selection: consists of having only the right index finger stretched and touch a node in order to select or deselect it. When selected the node or region changes is color to the color of the cluster that it belongs to;  
• Expansion: consists of having the right index finger and the middle finger stretched, and touch a node in order to show the region or touch a region in order to hide it and show it again has a node.  

Figure 2 shows the interface created in this work. Initially the connectome is represented has a node graph in the center of the screen and all nodes are grey. In the top left corner is displayed an aid message in other to let the user know what gesture is performing, in order to help him not to perform an interaction he does not want. Another visual aid was used when the user performs gestures with Pinch, a visual effect is represented next to the contact between the index finger and the thumb in order to let the user know that the Pinch is being performed, in figure 3 we see this visual effect.
Also, is displayed the name of the regions. To display the names, it was used the technique of Billboard. Figure 4 shows a name of one region.

**Figure 4. Region name.**

**User tests**
To support the conclusions of this study user tests were made, in order to collect data and information about the performance of the user-interface interaction. For this study was also carried out a questionnaire where users were asked to classify the interaction with the interface and how well manipulation gestures fit the interaction with the interface. The performance of user tests was important in the development of this study, it was through these tests that was possible verify if the goals of this study were reached because this study has as goals the creation of an interface that allows the visualization and navigation of the human brain connectome. These user tests consisted of performing a set of tasks. These tasks were designed in order to explore all the possible interactions with the interface. During the performance of the tasks it was recorded the times in seconds and number of errors committed during the execution of the task. The set of tasks to be performed were as follows:

- Task 1 - Use the selection gesture to select a node that is connected to the preselected node;
- Task 2 - Use the rotation gesture to highlight the preselected node;
- Task 3 - Use the zoom gesture to place the preselected node;
- Task 4 - Use the pan gesture to place the preselected node in the center of the screen;
- Task 5 - Use the expand gesture to view the region of the preselected node;
- Task 6 - Use the various gestures to view the region of the preselected node;
- Task 7 - Use the various gestures to place the preselected node in the center of the screen, select an adjacent node, and expand both regions.

**Table 1. Statistical results of recorded times.**

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Deviation</th>
<th>Min.</th>
<th>Max.</th>
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<td>3.60</td>
<td>2.08948</td>
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<tr>
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<td>9.13</td>
<td>8.38</td>
<td>4.76513</td>
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<td>7.18</td>
<td>3.58255</td>
<td>4.55</td>
<td>18.65</td>
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<td>4.76</td>
<td>2.80228</td>
<td>1.72</td>
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<td>Task 6</td>
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<td>19.04</td>
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<td>7.13</td>
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**Table 2. Statistical results of recorded errors.**

<table>
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<th>Std. Deviation</th>
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<th>Max.</th>
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<td>Task 5</td>
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<td>4.00</td>
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Also, it was performed a questionnaire where the user classified the interaction with the interface regarding the performance of each task, the performance of each method
of interaction and the overall performance of the interface. The questions asked were as follow:

- How do you rate the performance of the 1st task?
- How do you rate the performance of the 2nd task?
- How do you rate the performance of the 3rd task?
- How do you rate the performance of the 4th task?
- How do you rate the performance of the 5th task?
- How do you rate the performance of the 6th task?
- How do you rate the performance of the 7th task?
- Was the Rotation gesture appropriate to the interaction?
- Was the Zoom gesture appropriate to the interaction?
- Was Pan's gesture appropriate to the interaction?
- Was it easy to interact with the system?

In order to answer the first 7 questions, a semantic differential scale with 5 options was presented and presented as "Very Difficult" and "Very Easy" extremes. For the last 4 questions, it was also to present a semantic differential scale with 5 options and that presents as extremes "Strongly Disagree" and "Strongly Agree".

**Table 3. Statistical results of usability classification.**

<table>
<thead>
<tr>
<th>Questions</th>
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<td>Question 4</td>
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<tr>
<td>Question 5</td>
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<td>0.00000</td>
<td>5.00</td>
<td>5.00</td>
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<td>Question 6</td>
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<td>4.50</td>
<td>0.16048</td>
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<td>Question 8</td>
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<td>0.57124</td>
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<td>Question 9</td>
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<td>4.00</td>
<td>0.55251</td>
<td>3.00</td>
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</table>

**Discussion**

Thus, making an analysis of the times spent by the users to carry out the tasks we can conclude:

**Task 1:** All users were able to successfully complete the task within a reasonable time; Tasks 2, 3 and 4: In these tasks, almost all users were able to perform the tasks within a reasonable time, but the users who did not succeed within the time were considered in the statistical analysis as outliers, in this way if we exclude these outliers from the analysis we can conclude that the tasks are possible to perform with success within the expected time;

**Task 5:** In this task, some users take a little longer to perform it as can be seen in the box-plot of figure 5. One possible reason for these values to be slightly higher may be due to the difficulty of some users to have depth perception;

**Tasks 6 and 7:** Although these tasks are more complex to be performed, all users were able to perform them within a reasonable time, yet the tasks had fairly low median values compared to the expected values.

Through the table 2 we can see that tasks 1, 3, 4 and 5 were not registered errors during their executions, this was due to the fact that they are easier and intuitive tasks to execute. However, in Task 2 there was a user who made two errors, this fact was due to this user being part of a higher age group and in this task as was used the Rotation gesture which is a gesture a little more complex to execute.

In tasks 6 and 7, it was expected that there would be more errors, because they were more complex tasks to perform, yet task 6 was well performed by the users, having obtained an average error of less than 1 error. With regard to task 7, we can conclude that it was the most complicated task for the users being that it was more elaborate than the previous task, however this task performed sufficiently because it had an average of 1.14 errors.

By analyzing the responses given by the users to the usability questions we can verify, through the average, that all the answers obtained a rating equal to or greater than 4. In this way, we can conclude that the users found that it is an interface easy to interact and intuitive. As expected, users found the more basic tasks easier to perform compared to tasks involving greater complexity, yet these same tasks were also rated positively. Regarding the classification of the gestures, the users considered that the gestures of Zoom and Pan were fit to the interaction since all the users assigned the maximum classification. However, the Rotation gesture is a more complex gestuere obtained a lower rating, but nevertheless still obtained a positive rating of 4 in 5, the classification of this gesture is also justified by the existence of more errors in the execution of this gesture of the which is relative to others.

It is also important to highlight the result obtained in the last question regarding the ease of interacting with the interface and in this question users rated it 4 out of 5, which translates into an easy and intuitive interface to interact.

By doing a general analysis of the results obtained from this test we can conclude that the interaction with this interface was very positive since we have users to classify the interface with high usability, very reduced times in the accomplishment of tasks and few or no errors committed during the interaction.

**CONCLUSION**

This study consisted of creating an interface that allowed the navigation, exploration and interaction of the human brain's connectome. Due to the complexity of this dataset,
the need arose to explore alternative ways to manipulating it. Thus, it was hypothesized to use the Leap Motion device for interaction, this being a device that allows interaction in three-dimensional environments and is a device that can be easily acquired due to its affordable price. During the tests with the users the device proved to be easy and intuitive to interact with the majority of users, this fact was noticed that some users were able to perform tasks with the device quickly and with few errors, since the users had no prior training with Leap Motion. After performing the tests some users asked to continue interacting with the interface and it could be observed that the users improved their performance very quickly. The data obtained from the tests with users revealed that it is an interface that is easy to interact and has achieved the desired objectives. Sometimes users showed difficulty in perceiving depth when they performed the Selection or Expansion gesture because these gestures require touching the objects that the users intended to interact, users had to stretch their hands a little more than they anticipated, thus making a simple gesture to be a little more complex to perform. A limitation that occurred in the interface was in relation to the rotation gesture since it did not allow to rotate the connectome over the x-axis.

REFERENCES