

Assisting Neuroscientists in Exploring and Understanding Brain Topic Relations Using Augmented Reality

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Abstract

Exploring and investigating relations found in literature is an important process in research, but with large numbers of papers published each year, it becomes more challenging to maintain an overview of information. Immersive Analytics (IA) visualisations from the DatAR project can aid neuroscientists in performing complex relation exploration tasks such as finding semantically similar brain diseases and research topics that could explain this similarity.

DatAR is able to give users some insight into why and how these diseases are similar by showing brain topics that have been frequently co-occurring together with the diseases in the literature. This insight, however, is limited as the user can not investigate the relations of brain topics nor explore them, which are important tasks for a neuroscientist in order to better understand the interrelations between brain topics.

In this study we research how we can assist a neuroscientist to investigate and explore relations between brain topics in order to help them understand their interrelations and make it easier to find interesting and/or surprising relations that could prove to be a fruitful research area. Through a user-centered design approach, we formulate user tasks, user requirements and present an interface for immersive relation finding and exploring.

1 Introduction

Searching for information about relations in literature is an important but difficult and sometimes overwhelming task, especially when done manually. Taking the neuroscience domain as an example; to find out which diseases affect cognitive navigation and find out what these diseases have in common, scientists have to review multiple documents and analyse the interrelations of concepts themselves.

However, with the use of text mining and linked data, documents can be automatically scanned and allow one to search for specific relations relevant to their research. An example of a relevant relation would be the positive effects of physical exercise on cognitive function in patients with Parkinson's disease (PD) [da Silva et al. 2018]. This could indicate that patients with diseases similar to PD could also

improve cognitive function by exercising. Finding relations becomes more manageable this way, but exploring them remains a tedious task as one has to know what they are searching for beforehand.

Scientists could benefit from a tool or system which makes exploring and finding relations more accessible and have this information visualised as this can be more intuitive and easier to process [Aparicio and Costa 2015]. Systems exist that visually display these relations, such as the DatAR prototype [Troost et al. 2021]. DatAR makes use of linked data and Immersive Analytics (IA) to see whether 3D visualisations can support relation exploration in literature.

Troost's participants found the representational visualisations easy to grasp and an effective means for performing complex analytics, but remarks were made about the shallowness of shown relations during exploration [Troost et al. 2021]. His visualisation showed which brain diseases were semantically similar, but lacked information about why brain diseases were similar (Figure 1). Without this information, it is difficult to understand how these diseases are semantically similar to each other. To explain the similarity, users need knowledge about related brain topics such as the genes and neurotransmitters that are shared between diseases. An interface was made to retrieve shared brain topics between two diseases [Buiter 2021, Hendrickx 2021]. However, this interface is limited in its exploration capabilities as users can not get an insight on the brain topics shown. Potential interesting and/or surprising discoveries may be missed this way. Therefore, to further a neuroscientist's understanding of brain topic relations, they need to have the option to explore and investigate any relevant brain topic, rather than only the brain topics shared between diseases.

Our goal is to assist (neuro)scientists with exploring and understanding brain topic relations in the literature. We aim to make this process easier and more organised to help scientists form new insights and make interesting discoveries. Through a user-centered design process, we designed an interface that complements Huangfu's topic model (figure 1) and attempt to explain why diseases are semantically similar and show brain topics that might be interesting to investigate.

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methods differ as they find these relations through investigating correlation based on shared symptoms between brain diseases. We accomplish this through finding indirect connections between brain diseases (section 4.3).

HSDN extracts relationships from the PubMed bibliographic literature database and uses this as the data set, similar to the DatAR data set. In their manual performance evaluation, it is claimed that the vast majority of the relations found through text mining documents from PubMed are medically meaningful and direct. This could be an indication that relations investigated in DatAR are meaningful and direct as well.

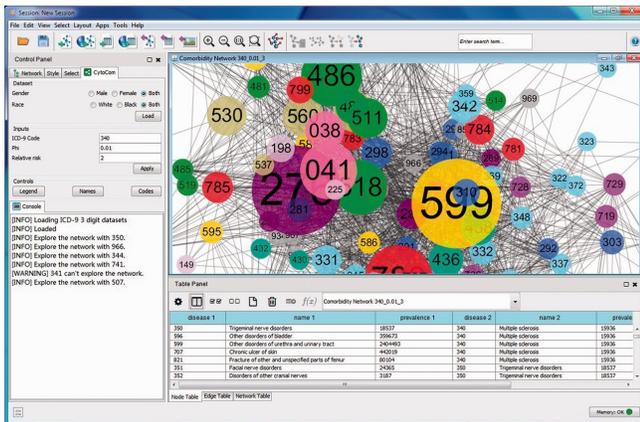


Figure 3. Figure taken from [Moni et al. 2015]. The disease network is shown in the center of the interface. Nodes in this network represent a unique disease, similar to the topic model in DatAR. The nodes are coloured according to a disease category. Edges between nodes in this network mean that the respective diseases are significantly comorbid.

2.3 Immersive Analytics

Immersive Analytics (IA) is the science of knowledge generation through analytical reasoning, facilitated by immersive human-computer interfaces [Skarbez et al. 2019]. IA aims to support people in understanding data and provide support for analysis and decision making [Marriott et al. 2018]. The principles of IA align with our goal to assist neuroscientists understand relations between brain topics. As a means to achieve our goal, we use Augmented Reality (AR) as our medium and design an immersive interface in DatAR. AR provides 3D depth cues which can be beneficial in data analytics, as suggested by multiple studies. [Ware and Franck 1994] studied the perception of 3D graphs with 2D and 3D (Virtual Reality) displays, where participants had to decide whether there was a path between highlighted nodes. Results show that participants had the same accuracy for graphs 3.0 times as large when using a 3D head-mounted stereo view. Motion parallax played the most important role herein. I.e.,

edges are better visible in 3D which can help with the identification of relations in a graph. In addition, [Kraus et al. 2020] demonstrated that multi-dimensional clusters are easier to identify in VR than in a 2D desktop display. VR graph layouts allow for faster decisions and fewer errors compared to a 2D interface [Kwon et al. 2016]. These studies show how effective immersive networks and 3D clusters are in their ability to assist scientists in perceiving information and could likely aid with relation exploration and understanding.

3 Method

We followed a user-centered design (UCD) process to optimize the usefulness and usability of our envisioned interface for its users [Vredenburg et al. 2002]. The process was divided into two cycles, where a cycle consists of four phases. A cycle consists of identifying problems (phase 1), formulating design requirements (phase 2), designing an interface (phase 3), and finally evaluating the interface (phase 4). After improving the design and requirements from the second cycle, we planned to evaluate and test the usability of the final version of the interface with a group of neuroscientists.

3.1 First Cycle

In the first cycle we identified problems that prevent the user from progressing in their research of brain topic relations. We investigated past studies done with DatAR and analysed the feedback from participants in these studies [Hendrickx 2021, Tanhaei et al. 2021, Troost et al. 2021] to determine a set of user tasks (table 1) and requirements (section 5). Consequently, we created a prototype interface with the intention of fulfilling these requirements.

The visualisation of brain topics in our interface takes inspiration from Hendrickx’s design (see figure 4). His design has been evaluated and deemed usable by information visualisation and IA experts, neuroscientists, and researchers with a biology background. Although improvements could be made to the visualisation to make it more readable and clear, the design serves its purpose and target audience. Furthermore, keeping the design in DatAR consistent is beneficial for the user to help keep intentions and expectations of widgets clear.

In the last phase of this first cycle we asked K.N. Gracy, a neuroanatomist, to verify our collected requirements and evaluate the prototype interface. The prototype was only able to show and explore relations in DatAR at this stage. Because of the COVID-19 outbreak, evaluations took place online through screen-sharing. We realize that the immersive aspect of the interface is lost by doing online evaluations, however, this allowed us to focus more on the design and usability aspect. During an evaluation, we let Gracy interact with the DatAR environment by giving her input control. In order to get a better understanding of how the interface could

be used in the workflow of a neuroscientist, we prepared a storyboard that incorporated user tasks I1 and I2 (table 1). Finally, we showed a drawn concept design of a brain topic network visualisation which we discussed the practicality and usability of.

3.2 Second Cycle

In the second cycle we adjusted the user requirements and the design of the interface, based on the feedback received from the first evaluation. The prototype interface was able to show and explore relations, and generate a network visualisation for brain topics. We verified the new user tasks and requirements from the first evaluation. The second evaluation was taken with the same neuroanatomist as the first evaluation. The adjustments made to the design after the second cycle resulted in the final design.

3.3 Final User Evaluation

After the second cycle we incorporated Gracy’s feedback into our final design and planned to evaluate this with neuroscientists. We wanted to evaluate the usability, practicality, and estimate how successful the interface is in accomplishing the set of user tasks we constructed. An important question to ask is whether the 3D depth cues in AR give neuroscientists an added value during relation exploring and understanding. If so, are neuroscientists willing to consider using a head-mounted AR display in their workflow? However, due to unforeseen circumstances, evaluations could not take place. We give further elaboration in section 8.

4 Defining User Tasks

To answer our research question on how we can assist neuroscientists with exploring and understanding brain topic relations, we need to know which tasks they are trying to accomplish by exploring these relations. We construct a list of user tasks that support exploring and understanding brain topic relations. The user tasks in this list are a combination of tasks collected from [Troost et al. 2021] (labeled as **PX**), tasks we had in mind for the neuroscientist initially (**IX**), and tasks constructed based on evaluations done in this study (**EX**). We give context and elaborate on each user task in the subsections below. A complete overview of these user tasks can be found in table 1.

4.1 Find/explore known and unknown relations.

During research, a scientist might need more knowledge on a brain topic that they are researching. E.g., a neuroscientist is researching neurotransmitters and would like to know which proteins are related in order to give the scientist a place to start an investigation. Showing relevant brain topics can therefore serve as an orientation on the research area.

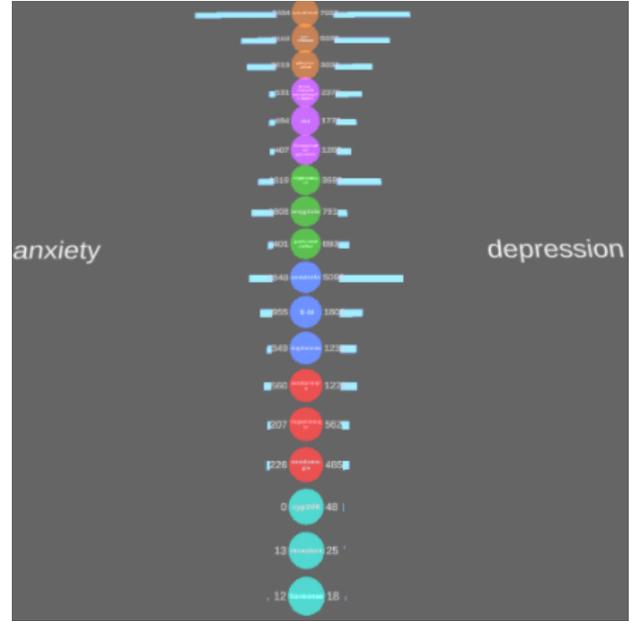


Figure 4. Screenshot from DatAR (September 2021). The interface shows the overlapping topics between two brain diseases. The coloured spheres indicate a brain topic from a certain category. The histogram shows how many results are found with the respective disease.

"The analyst must initially learn about the different topics and contents within the data and decide what to investigate first." (Görg et al., 2014).

4.2 Get context on a brain topic in regards to a set of other topics.

Users need assistance in getting context during relation exploration as brain topics on their own can be ambiguous and thus provide no useful information for the user. The brain topic relations that are interesting differ depending on the context of the research. For example, a neuroscientist only wants to know how a certain neurotransmitter works in the Amygdala and not in the Hippocampus. Understanding the right context can therefore help filter out unnecessary information and is an effective way to segregate complex associations [Gopalakrishnan et al. 2019].

4.3 Find indirect relations between brain topics.

This user task is inspired by Cunqing Huangfu, a neuroscientist. An indirect relation means that for some brain topic A, there is no direct co-occurrence with brain topic B in literature. However, through inference of one or more brain topics co-occurring with both A and B, a relation between brain topic A and B could be hypothesized [Goodwin and Johnson-Laird 2008]. Indirect relations may be interesting to explore as these could indicate new research areas or reveal other discoveries. Through indirect relations, treatments

were found that alleviate symptoms of diseases they were not intended for [Fishilevich et al. 2017][Weissenborn et al. 2015].

4.4 Find common overlap between brain topics.

Analysing the relations that brain topics have in common could bring new insights into the relations and the brain topics themselves. Finding the commonalities in a set of brain topics allows users to investigate the similarity of them and can also help accentuate the differences between brain topics. Investigating the commonalities and differences of brain topics can contribute to a better understanding on brain topics and give room for new research areas, such as the research done on Autistic Spectrum Disorder and Attention Deficit Hyperactivity Disorder [Craig et al. 2015].

4.5 Get a sense of volume and relatedness of research done in neuroscience.

To quickly analyse which research areas have been well covered and which require further investigation, an overview of the volume and relatedness of brain topics is interesting to see. DatAR already provides an overview for relatedness through the topic model, where it gives users a sense of how semantically similar diseases are and explain the possible relatedness of diseases. This user task aligns with the feedback received from Hendrickx's participants, who used his interface in order to get a sense of scale for research done in the field as well.

4.6 Locate relevant brain regions in the brain model when exploring a brain topic.

Visualising the relevant brain regions helps a neuroscientist think about the neural pathways and is an intuitive way to view how brain topics are physically related to each other in the brain. It could be that there is a strong relation between two brain topics while they are physically far apart from each other, according to Gracy. This is something she would be very interested in, and would want to investigate.

4.7 Find brain topics that frequently or rarely co-occur with other brain topics in literature.

Huangfu revealed that brain topics that frequently co-occur with a brain disease in literature may indicate a wide consensus on a relationship. Knowing which brain topics often co-occur can help scientists verify the findings of other researchers and also indicate commonly known domain knowledge scientists should be familiar with. On the other hand, topics that rarely co-occur with other diseases could offer fruitful grounds for investigation [Troost et al. 2021]. While Huangfu mentioned diseases specifically, we hypothesize that the same statements hold true for brain topic to brain topic co-occurrences. Thus an overview for viewing these most and least co-occurring brain topics could prove to be helpful for the user.

4.8 Find out which cognitive functions are associated with a brain topic.

It is helpful for neuroscientists to know which cognitive functions have a relation with a brain topic, as it could improve the understanding of relations by giving meaning to the brain topic. A boolean search could with relative ease, reveal the cognitive function(s) related to a brain topic. However, acquiring the same knowledge for the vice versa is not as trivial. Results for brain topics that are related to a cognitive function seem to be harder to find through this manner, which could lead to potentially obscuring knowledge. Furthermore, in Hendrickx's study a possible correlation was found between the cognitive functions that were related to two semantically similar diseases. Diseases were closer to each other in the topic model when they had more cognitive functions in common, which could explain their semantic similarity [Hendrickx 2021].

4.9 Locate relevant diseases in the topic model when exploring a brain topic.

By highlighting the diseases in the topic model, a user can see an overview of relevant diseases that are associated with a brain topic. This could help explain the semantic similarity of diseases when two or multiple diseases are highlighted and close to each other. When two highlighted diseases are far apart from each other, it could be interesting to investigate how the explored brain topic is associated with the two diseases.

5 User Requirements

The user requirements listed below are collected from the two evaluations done during the user-centered design process. Based on the discussion we had with Gracy during these evaluations, we translate her feedback into user requirements.

UR 1: Exploration of Brain Topics

During the exploratory phase, users should see the information of brain topic relations at a high-level first and get an insight on research done in that field. When users discover an interesting or surprising relation, they should have the option to narrow down on the brain topic and get more details on the relation. They could then investigate whether there are other brain topics with stronger relationships.

UR 2: Brain Topic Category Filtering

The user should be able to quickly spot relations of interest, but should not get overwhelmed with too much information. Not every piece of information is required at all times, but can be retrieved when necessary. E.g., a user might only be interested in proteins and diseases, thus the interface should support the filtering of information that conforms to the user's needs.

User Tasks	Source	Section	ID
<i>Find out which brain topics are frequently or rarely mentioned with a brain disease in literature.</i>	Cunqing Huangfu [Troost et al. 2021]	4.7	P1
<i>Get context on a brain topic in regards to a set of other brain topics.</i>	[Troost et al. 2021]	4.2	P2
<i>Find indirect relations between brain topics.</i>	Cunqing Huangfu	4.3	I1
<i>Find/explore known and unknown relations.</i>	Initial	4.1	I2
<i>Locate relevant diseases in the topic model when exploring a brain topic.</i>	Initial	4.9	I3
<i>Find common overlaps between brain topics.</i>	K.N. Gracy	4.4	E1
<i>Find out which cognitive function(s) are affected by a brain topic.</i>	K.N. Gracy	4.8	E2
<i>Get a sense of volume and relatedness of research done in neuroscience.</i>	K.N. Gracy & [Hendrickx 2021]	4.5	E3
<i>Locate relevant brain regions in the brain model when exploring a brain topic.</i>	K.N. Gracy	4.6	E4

Table 1. An overview of relevant user tasks collected from [Troost et al. 2021] (labeled as **PX**), initial tasks we had in mind for the neuroscientist (**IX**), and tasks constructed based on evaluations during the UCD process (**EX**). E3 aligns with feedback from Hendrickx’s participants.

UR 3: Data Visualisation

Data should be visualised graphically as this helps the user better understand the information displayed. Using shapes and colours allows users to interpret qualitative values, rather than quantitative values [Aparicio and Costa 2015]. Visualisations can help users see meaningful units and relationships in data when it is organised such that users can focus on a relevant subset of data and avoid clutter [Woods et al. 2002]. As stated by Woods et al.: "Clutter results from a failure to design the elements into a coherent perceptual organization or from a failure to manipulate the elements so that the resulting perceived organization captures a meaningful organization in the referent domain."

UR 4: Progress Tracking

With traditional literature exploration where users would use a search engine such as PubMed or Google Scholar, it is easy to get lost in documents and forget where connections are found. The interface should therefore assist the user with their progression on how they explored the information and got to the current state of the system.

UR 5: Retaining Context

It would be useful for the user to retain context for orientation when they are investigating a brain topic and relevant relations in more detail. When exploring relations, previous results should therefore not be removed or replaced.

UR 6: View Relatedness of Brain Topics

When researching the brain, it is helpful for the user to see where in the brain a certain disease or gene is found. This gives the user a visual overview of relations found in specific brain regions and is especially useful when analysing neural pathways. E.g., when researching the disease Alzheimer Disease which affects parts of the brain involved in memory such as the Cerebral Cortex and Hippocampus, the user

should see what behaviors are involved in those specific brain regions so they can anticipate the complications associated with Alzheimer Disease. Gracy, the neuroanatomist from our evaluation, was specifically interested in the location of transmitters and receptors in the brain and how the activation of them affects the brain.

"I think what is so delightful about this (DatAR), is that you can start to see why it all matters and how it is all connected. We can go up really high-level, start from the top and see this enormous map of diseases. Even as an expert, you would need this kind of orientation." (K.N. Gracy).

6 Design Rationale

We discuss the decisions made for the visualisation and interaction aspect of our interface. The final design is shown in Figure 5. We took a look at the existing interface in DatAR and analysed how our prototype interface could complement existing features. Furthermore, we took feedback from various DatAR users into consideration who have participated in evaluations in either this study or past DatAR studies. We prioritised feedback regarding functionalities relevant for our study first. Note that we were not able to incorporate every feedback into the final design because of time constraints. Instead, we discuss this in Future Work, section 10.

6.1 Widgets

Widgets in DatAR are interactive objects which allow users to quickly use a predefined query on a data set and visualise results. We implemented our own widget in the selection of available widgets in DatAR, called the Brain Topic Relation Explorer (BTRE), as seen in Figure 5 (4). BTRE is similar to Hendrickx’s Brain Disease Co-occurrence Explorer (BCDE). Where BCDE takes two brain diseases as input, BTRE takes only one brain disease as an input. This gives users the option to focus on one disease. After evaluating BTRE, it would

User Requirements	Abbreviation	Section	ID
<i>Information Visualisation.</i>	Visualisation	5 & 6.2	UR1
<i>View Relatedness of Brain Topics.</i>	Relatedness	5 & 6.2	UR2
<i>Brain Topic Category Filtering.</i>	Filtering	5 & 6.3	UR3
<i>Exploration of Brain Topics.</i>	Exploration	5 & 6.3	UR4
<i>Retaining Context.</i>	Context	5 & 6.4	UR5
<i>Progress Tracking.</i>	Progress	5 & 6.5	UR6

Table 2. An overview of user requirements collected from the evaluations with a neuroanatomist during the UCD process.

be ideal to integrate specific functionality from BCDE into BTRE as the visualisations connect well together. BTRE was initially its own separate widget to make prototyping easier. Moreover, we expect it would reduce cognitive load on the user when all relevant functionalities for exploring and understanding brain topic relations are found in one place, rather than having a separate widget for each functionality. This may also prevent confusion as the BCDE and BTRE visualisations are comparable.

6.2 Visualising Relations

To assist the neuroscientist in understanding the relations found between brain topics, we represent the relations in a visualisation that is a combination of a bubble chart and a graph (7) (**UR1: Visualisation**). Bubble charts and graphs are commonly used for visualising relational data. The former puts emphasis on the category of data through colour and size. The latter can intuitively reveal a network of relations. We refer to this combination as bubble graph in this document for simplicity. Another type of visualisation that could be considered are (non-ribbon) chord diagrams which are used to show many-many relationships in data as well. However, the chord diagram translates less effectively to the AR environment because of its 2D nature.

We think the bubble graph is a suitable visualisation for helping the user understand relations between brain topics. Arguably, it is also able to provide context on the topics and give the user a sense of volume and relatedness (**UR2: Relatedness**). By utilizing size and locations in virtual space, it can intuitively tell the user how much research has been done and which topics are most often mentioned together. The size could represent the amount of research done and the location indicates the relatedness of brain topics, which can give more context than a list view could.

The bubble graph uses force-directed placement for nodes, an idea inspired by [Fruchterman and Reingold 1991] that attempts to produce aesthetically-pleasing graphs. Compared to other graph drawing techniques, a force-directed graph works reasonably well without the user having to fiddle with options and parameters. Moreover, it is able to visualise in negligible running time. Most time is spent on retrieving data for visualisation.

6.3 Interaction

Interface. The DatAR project functions in an AR environment. As such, one could hypothesise that AR interactions should be used where possible as it may pose to be more natural. Therefore, in our design we chose to use hand gestures in the interaction where possible, instead of virtual buttons. Both types of interactions have their benefits and drawbacks, thus a balance needs to be found between the two types of interaction. Hand gestures are best suited for manipulating objects in the virtual space, such as moving and rotating, similar to interaction with objects in the real world. Buttons are excellent for executing precise commands such as filtering and sorting data. For this reason, we take inspiration from Hendrickx’s interface which allows users to filter information on brain topic category (e.g. Brain Region, Neurons) by pressing buttons on a button panel (**UR3: Filtering**). Most participants from Hendrickx’s study were able to use the button panel intuitively, succeeding in enabling and disabling the filters.

Exploring Relations. When investigating a brain topic, the visualisation initially shows, if available, the top 3 relations it has with brain topics from other categories (1)(2) (**UR4: Exploration**). The initial visualisation is limited to 3 relations of each category to keep the visualisation within the bounds of the vertical field of view (FOV). Showing just the top 3 relations of each brain topic category initially seems to suffice for a high-level overview of relations for users, based on feedback from our and Hendrickx’s evaluations. With the initial list (1), users can find known and explore unknown relations. Relations can be explored by grabbing the brain topic which the user wants to investigate the relations of. Depending on which view is selected in the menu, a new list or bubble graph (see subsection 6.2 below) will be generated for relations, next to the grabbed brain topic (**UR5: Context**). We incorporate a hand gesture in this aspect of the design as this is in line with the rest of the interaction done in DatAR. Another option to consider is to visualise relations when a brain topic is clicked on, similar to a button. However, we postulate that the grabbing gesture is more intuitive and gives the opportunity to let the user move the generated lists to any desired place in the virtual environment.

When exploring a brain topic, BTRE retrieves the top 3 most co-occurring relations of the explored brain topic for each brain topic category in both the list and bubble graph view; similar to retrieving brain topics for the initial list. The bubble graph is less restricted in the vertical FOV than the list view and can thus show more brain topics. We decided to show only the top 3 relations per category as this is sufficient for a high-level overview and prevents the bubble graph from being too overcrowded. Most importantly, this keeps the generation of the bubble graph within a reasonable time.

Explored relations do not necessarily have a relation with the input disease or other brain topics shown before exploring (2). This allows users to find indirect relations with diseases and brain topics through exploration. Every brain topic in the list view can be explored which can create a tree-like structure of relations. We let the user only explore brain topics in the list view as the bubble graph is a visualisation where brain topics can be densely packed together, making it difficult to expand brain topics properly. This could also be a hindrance when users want to move the bubble graph around in the virtual environment, as the interaction could be mistaken for generating a new list or bubble graph by the system.

6.4 Contextualisation

When investigating the relations of a brain topic, we generate a new visualisation next to the existing overview of relations as opposed to replacing the existing overview (**UR5: Context**). From evaluations we learned that the existing overview is preferred to retain context during relation exploration.

6.5 Exploration Progress

To make it clear to the user which visualisations belong together, a subtle transparent pink connection line is shown between two visualisations (3) (**UR6: Progress**). We decided to make the line transparent as we did not want the connection line to be conspicuous and distracting from the visualisation. The user should be able to find the connection when looking for it.

6.6 3D Model Highlighting

The DatAR environment can provide the user with a topic model and a brain model. The former shows the semantic similarity of brain diseases through visuospatial data representation, and the latter shows the central points of brain regions in the Scalable Brain repository [Troost et al. 2021]. The 3D models can be used during relation exploration to show the user diseases or brain regions associated with a brain topic of interest (5)(6). Users can see at a glance how semantically similar the diseases are in the topic model, or see the physical location of brain topics that they are investigating. This encourages investigating interesting or surprising

findings herein. By highlighting relevant data points in the models while exploring brain topics, users see which diseases or brain regions are relevant for their research. This visualisation can help users analyse brain topic relations.

7 Implementation

Querying. The interface is implemented in the DatAR framework as a widget, using Unity (v2019.3.15f2¹). When BTRE takes a brain disease as input, it will query for topics that are related to the disease in the data set provided by Linked Brain Data (LBD²). Queries are sent through a SPARQL endpoint which returns a JSON object with the requested results.

Data Set. The LBD dataset consists of triples, containing data such as the numbers and sentences of brain topic co-occurrences found in literature. LBD only considers the co-occurrences in abstracts and titles. BTRE requires the following data:

- Brain Topic A
- Related Brain Topic B
- Number of co-occurrences between A and B.
- Brain Category for A
- Brain Category for B

Bubble Graph. While Fruchterman and Reingold used an algorithm to calculate the position of nodes, we simply make use of the physics engine integrated in Unity. We implemented a slight adjustment to the force-directed bubble graph, where brain topics (nodes) repel or attract each other based on whether co-occurrences are found between two brain topics. As time passes by, more drag is added to nodes in order to stabilize the bubble graph. With the addition of force-direction, we intend to create visual clusters in the graph to indicate a group of related brain topics and for easier identification of related brain topics. The size of nodes in the graph is based on the number of co-occurrences that each node has with the expanded topic.

8 User Evaluation

Unfortunately, we were unable to do the evaluation for the final design in this study because the data set used for our interface became unavailable for use. An attempt was made to recreate and use a new data set, however, after three months it became clear that more work had to be done in order to get the DatAR system working again. Because of time constraints, we decided to finish this thesis with the work we had done thus far.

¹<https://unity.com/>

²<http://www.linked-brain-data.org/>

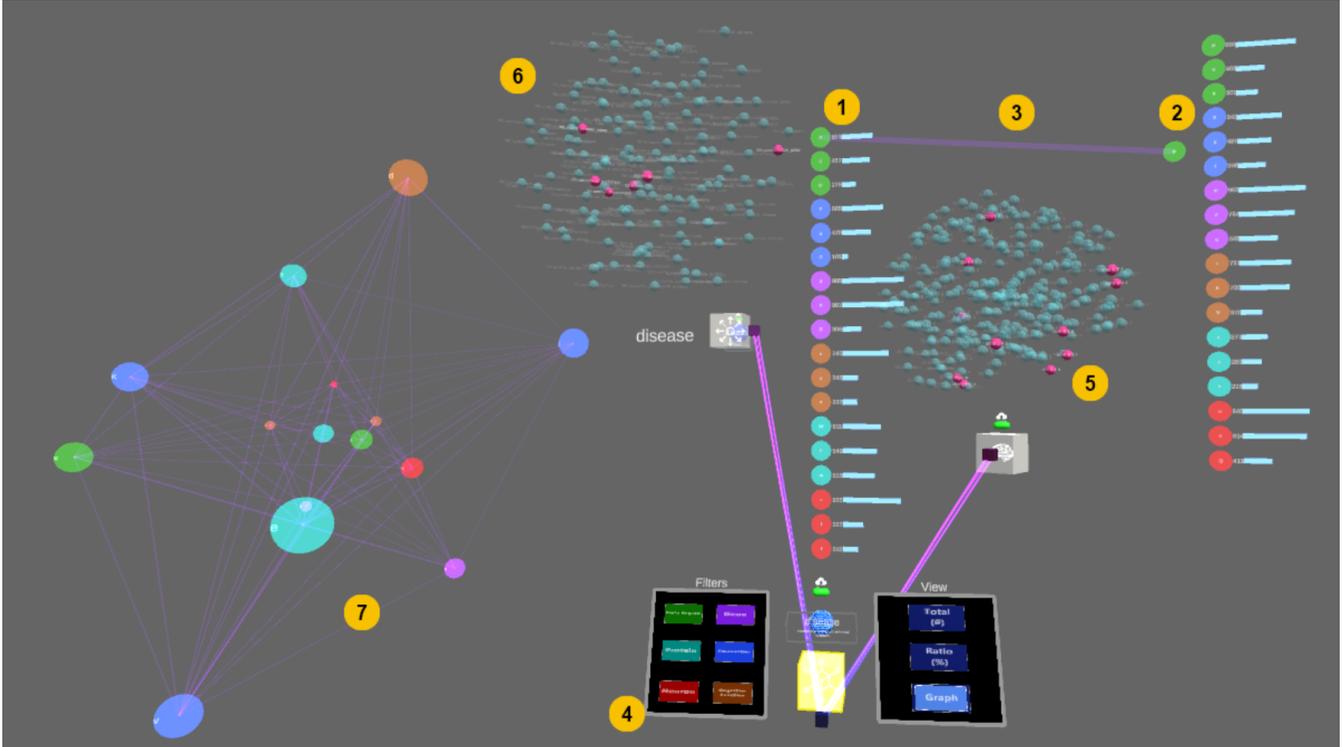


Figure 5. The interface for exploring and understanding relations between brain topics. The numbers in the figure highlight the following aspects in the interface, along with the user tasks they fulfill: (1) Initial topic list $[P1, I2, E2, E3]$, (2) Expanded brain topic. Relations of this expanded brain topic is shown as a list to its right $[P2, I1, I2, E1, E2, E3]$. (3) An edge between the expanded and its duplicate. (4) The menu panels of the widget. Left panel is for filtering on brain topic category, right is for showing different views such as the list or bubble graph view. (5) The brain model which highlights brain regions (in pink) that are affected by (2) $[E3, E4]$. (6) The topic model which shows diseases (in pink) which have a co-occurrence with (2) $[I3, E3]$. (7) A bubble graph view of an expanded brain topic $[P1, P2, I1, I2, E3]$.

9 Conclusion

We analysed past DatAR studies and conducted evaluations with a neuroanatomist in this study. We provide a set of user tasks (table 1), user requirements (table 2), a design (figure 5) and its rationale (section 6) for assisting neuroscientist in exploring and understanding brain topics relations in neuroscientific literature. The benefit of adding augmented reality in the workflow of a neuroscientists remains to be evaluated. Our interface consists of two novel additions to DatAR, which are the bubble graph and the relation exploration feature. The bubble graph is designed to give users a quick overview of related brain topics in clusters. The relation exploration feature allows users to explore brain topic relations which could improve the user’s understanding of brain topics. New knowledge can be acquired and indirect relations may be found through these visualisations. This could potentially provide interesting discoveries and research areas to investigate. Unfortunately, we were unable to do an evaluation on our final interface design and therefore, we can not confidently answer how successful our

interface is in accomplishing the user tasks we constructed. However, the neuroanatomist in our evaluation has shown interest and enthusiasm in the iterations that the interface has gone through. Immersive 3D visualisations can be a valuable medium to help analyse relations between brain topics and have been found to provide a clearer view in comparison to 2D displays. The 3D depth cues provided in AR can aid in the identification of edges and clusters in the bubble graph design. Therefore, we believe that immersive 3D visualisations have a place in the workflow of the neuroscientist, and that IA has strong potential to assist neuroscientists in exploring and understanding brain topic relations.

10 Future Work

In this section we describe future work that could be done in DatAR in order to further assist a neuroscientist in their research workflow. We propose ideas on the design and interaction aspect of BTRE.

Bubble Graph

The bubble graph design needs to be evaluated for its usability and practicality when a new data set can be used in DatAR. If the bubble graph is considered useful by neuroscientists, improvements could be made to its visualisation to make the identification of relations clearer and easier. When a brain topic has many relations in a graph, the edges between nodes can make the visualisation look cluttered. One method that helps to reduce clutter is to bundle edges [Peng et al. 2012]. Bundling edges makes the bubble graph look more organised and puts more emphasis on the relations at node level. This could be complemented with highlights in the bubble graph to let the user focus on a subset of brain topics, similar to the highlighting of nodes and edges in the tool InfraNodus [Paranyushkin 2019]. These techniques will become more useful as the graph grows larger.

List View

Horizontal Layout. Hendrickx’s design of the list view mainly uses the vertical axis to display relations. In his work, he states that the verticality of the visualisation does not scale well and that the vertical FOV in AR is limited. Hence, a design decision could be to give the user the option to move more elements to the horizontal axis. For example, brain topics could be shown in a 6x3 layout, where a brain category is shown on the X-axis and the top 3 relations in that category on the Y-axis (Appendix A). This removes the need to look up and down the visualisation and may improve the practicality of the interface as every retrieved brain topic would then be clearly shown in front of the user.

An aspect to consider, is the loss of the co-occurrence histogram that is visible when brain topics are displayed in a row (18x1) or column (1x18) layout (Figure 4). To remedy this, coloured bars could be used to add more visual aid for comparing the number of co-occurrences. E.g., a light-blue to light-red gradient for low to high numbers of co-occurrences respectively (Appendix A).

Parallel Coordinates Plot. In the current visualisation design, only the bubble graph is able to show the relatedness of various brain topics together. It could be useful to show the relatedness in the list view as this can provide a different insight on the relations of brain topics. Inspiration can be taken from a parallel coordinates plot to visualise the relations. While parallel coordinates are typically used to compare multivariate numerical data, in our interface we could let users compare the relations between two lists of brain topics (Appendix B).

Information Visualisation

Filtering. Users should be able to apply filters to better control what information they want to see. In our interface, filters could be applied to find brain topics within a range

of co-occurrences or find brain topics that must have a co-occurrence with some specified brain topic X.

Brain Topic Description. Some brain topics in the data set use an abbreviation, such as ACP for Acyl-Carrier-Protein. During evaluations, we got feedback from Gracy that it would be useful to see what these abbreviations stand for and how they are defined. It is unlikely that a neuroscientist will know all the different names used for brain topics, even in relatively close-by neuroscience research fields. A possible design in BTRE could be to implement a pop-up text area with relevant information on the brain topic with descriptions from MeSH³. A pop-up would then appear through head-gaze or hovering over a brain topic with the hand.

Appearance. To improve the usability of the design, larger text sizes and the usage of icons should be considered. Combining colours and icons for brain topic categories could help users make them easier to recognise. Dotted lines between brain topics could be used to indicate an indirect relation.

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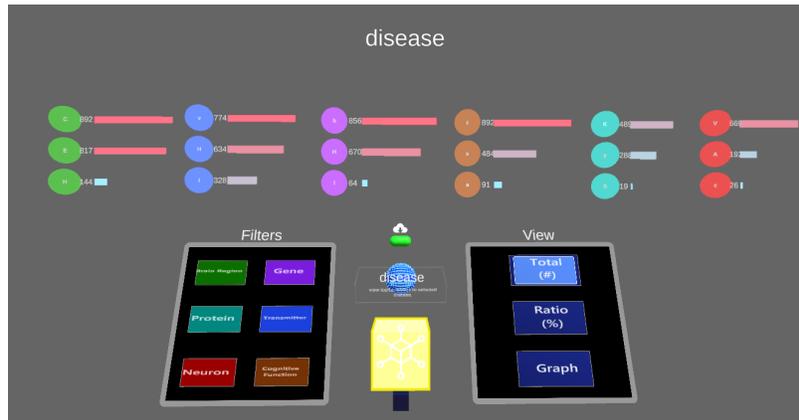
³<https://www.ncbi.nlm.nih.gov/mesh>

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Appendices

A Horizontal Layout

An example design for BTRE that is using the horizontal axis to display brain topics in a 6x3 layout. A gradient of two colours is used to indicate the number of co-occurrences. Brain topics with higher numbers of co-occurrences will have a light-red bar. The colour of the bar will gradually become more light-blue as it approaches the minimum number of co-occurrences found.



B Parallel Plot Design

Inspiration is taken from a parallel coordinates plot for this design. The figure shows an example of how relations could be shown between two lists. A brain topic from list A is expanded and has generated list B. An arbitrary brain topic is selected from list A to show which brain topics in list B it is related to. Brain topics can have many relations and therefore, users should be able to select which brain topic they want to see the relations of, in order to prevent clutter. In the figure, the selected purple brain topic in list A has four relations with brain topics in list B. The red brain topic from list B has five relations with brain topics from list C.

