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Explaining Dementia Using Graph Theory and Machine Learning

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Abstract: Dementia is a central nervous system neurodegenerative disease. Dementia has been discussed around different types. Among all, Alzheimer's disease (AD) and vascular dementias (VaD) are the commonly caused disease. There is a huge research gap that graph theory has rarely been followed to explain the cognitive systems functioning particularly diseases like dementia. Thus, theoretical models of graphs can be used to interrogate the cognitive systems and the likely presence of dementia to understand the reasonings behind and thus the treatment. In this paper, three studies have been discussed in which dementia is investigated through graph theory and machine learning by using theoretical foundations to support the evidence. The first study discusses the significance of graph theory techniques and its coined ideas. There are fundamental designed parameters; connectivity, diameter vertex centrality, betweenness centrality, clustering coefficient, degree distribution, cluster analysis and graph cores. In addition to this, these are featured to analyze magneto-encephalography data to find out functional network intensity in Alzheimer's disease affected patients. The second study explores particularly the changed structure of Alzheimer's disease. The third study coins the significance of machine leaning philosophy that paves the way for the black box and diagnosis.

Keywords: Dementia, Graph theory, Machine learning

1. Introduction

Dementia is a central nervous system neurodegenerative disease. Dementia has been discussed around different types. Among all, Alzheimer's disease (AD) and vascular dementias (VaD) are the commonly caused disease.

AD impact lives of both patient and caretaker at such a level that social activities and quality of life are negatively affected. However, dementia's etiology and pathology are still under study to explore it more. Its diagnosis is at no less than clinical level. Till date, no proper treatment has been diagnosed for the treatment of dementia.

There are several different types of loss of cognitive functioning to such an extent that it interferes with a person's daily life and activities. Some dementia patients cannot control their emotions, and their personalities may change after experiencing dementia. The correlation between different types of cognitive functioning and range of age or types of AD is shown in the following chart.

Dementia has been found to affect elderly people with age above 65 years with a larger proportion to women. In some of the cultures, it has rarely been found. However, dementia has been found to underlie

a common neuropathology. Research in neurochemical and neurobiological literature has advanced the findings on reasons of dementia.

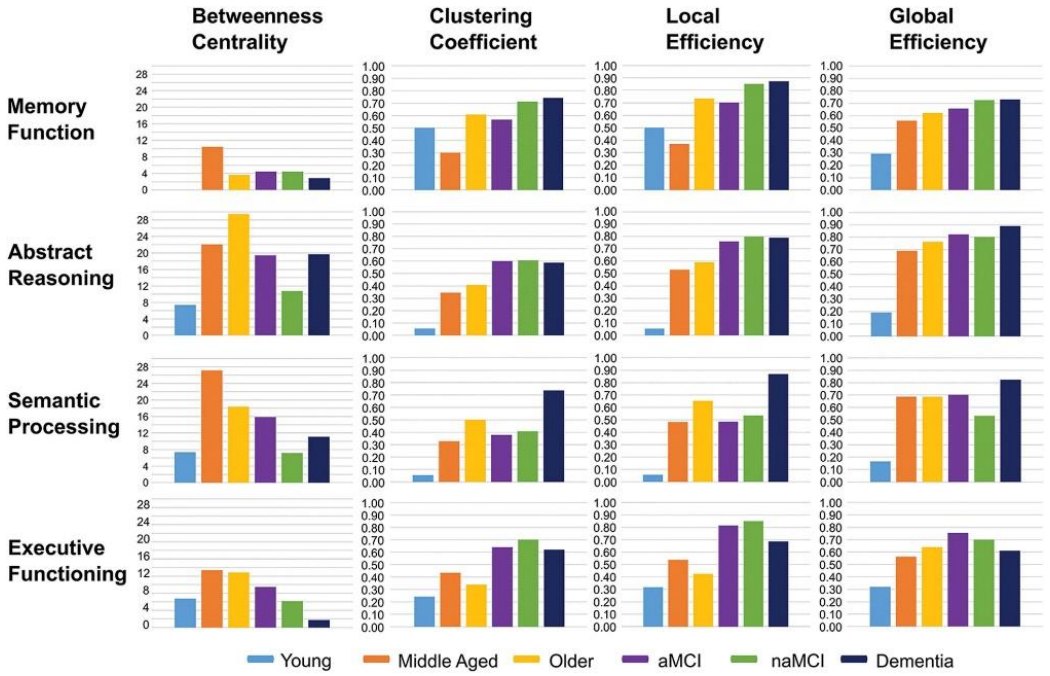

Figure 1. Bar charts showing the average network metrics for each cognitive domain across participant groups (Wright, 2021).

In this investigation, functional imaging has played a role in identifying underlying biomarkers, this led to improvement in neurotransmitter functions. This advancement has also enhanced the intervening role of amyloid production and deposition besides reducing risk factors associated with it such as depression, hypertension, and hypolipidemia. In addition to that, testing and counseling at earlier stages of dementia is the recent development in the advanced treatment. Even though new treatment has been identified there is much remaining to be done in the area of disease management and understanding of dementia through graph theory and machine learning.

Graph theory is a mathematics branch and is mostly used to investigate the structural and functional networks for the AD dementia disease (Griffa et al., 2013; Tijms et al., 2013b). These findings are motivated based on research that AD has the properties to bring changes in brain connectivity due to synaptic functional loss (D3Amelio and Rossini, 2012; Whitwell et al., 2012). Graph theory allows system to be quantified so that it can be described in terms of network. Network is the collection of entities known as nodes which is again the serial connection of edges (Bondy and Murty, 1976). These cognitive domains are although distinct, but these cannot work in isolation. In fact, when these cognitive dimensions work interdependently, it enhances the functioning and performance of most of the tasks. This kind of interdependency and separation in cognitive abilities make possible the understanding of conceptualizing cognitive networks. This allows for monitoring of tasks performance that connects with edges with nodes for the correlated performance (Garcia-Ramos et al., 2016).

There is a huge research gap that graph theory has rarely been followed to explain the cognitive systems functioning particularly diseases like dementia. Thus, theoretical models of graphs can be used to interrogate the cognitive systems and the likely presence of dementia to understand the reasonings

behind and thus the treatment.

Graph theory helps to quantify networks of complex pattern. In the framework explained through graph theory, nodes and edges can be identified in the network system. In that, number of edges represent and identify the measures that are to be calculated to understand local and global property connection (Rubinov and Sporns, 2010).

It is very interesting and appealing to apply graph theory for studying AD because pathology of AD advances in a serial way throughout the brain (Braak and Braak, 1991). It also suggests that connectivity characteristics may change in the same fashion of order over the disease patterns with utility of diagnosis.

Dementia Alzheimer and other diseases like Parkinson have posed challenges for the clinicians. The applied research in this context is highly needed despite the existing studies. It is the reason that modern techniques such as machine learning is being integrated to understand and explore dementia and other diseases.

These complex diseases are not easy to diagnose, and it is highly critical to identify the symptoms behind as these diseases and thus symptoms overlap on many grounds. Therefore, it is important to examine the complex diagnostic processes accurately with modern techniques and computer-assisted programs and latest theoretical models.

Therefore, this piece of research will explain dementia by using graph theory and machine learning.

Below, we will discuss two main studies in which the dementia has been explained through following such frameworks and foundation.

2. Research Design, Data collection and analysis Methods

Alzheimer's disease neuroimaging initiative (ADNI) database will be utilized for the selected subjects of the study. May 2013 is selected for the data analysis as it was available. ADNI is considered a discursive idea to coin the evolvement of the MCI and AD. It was announced through bilateral relations. The MRI data is utilized under the initial phase (ADNI-1). The studied subjects show valid ideas for the collected data for future directions. The participatory institutions hashed over a study approved by the board. The data was considered pseudonymous before the utilization. The subjects were utilized under the medical structure mostly freed from neurological and psychiatric conditions. This also went through the cerebrovascular risk analysis. The given site is added for further extractions. The groups were included in the data set for the current study. 127 cognitive normal people remained at baseline for 3 years on cognitive structure. Furthermore, 104 people were detected with MCI for 3 years (Stable MCI group). In addition to this, 106 were detected with MCI and developed AD- dementia for 3 years, and 108 with AD dementia. All the participants were led through the MRI scan and controlled with the Clinical Dementia Rating (CDR) Scale (Morris, 1993).

2.1 Study 1

First study discussed here is the research conducted by Bhagyashree et al., (2018).

It has been found that occupational and formalistic organization is renovated in the human brain network to Alzheimer's disease. This study promotes further graph theory execution. It also opines the fundamental criterion of connectivity, diameter vertex centrality, betweenness centrality, clustering

coefficient, degree distribution, cluster analysis, and graph cores. In addition to this, these are featured to analyze magneto-encephalography data to find out functional network intensity in Alzheimer's disease-affected patients. Both weighted and un-weighted undirected/ directed graphs are recorded that are determined by occupational connectivity analysis for the intentions of network and vertex centrality. The modal could also be judged by provided lost links, the intensity of the parietal region, and derailed synchronization. Furthermore, the temporal region attains the centrality loss found in cases of Alzheimer's disease which is clinically significant. The research has shown that graph theory establishes the characteristic path length and clustering for the use of studying the phenomenon of electroencephalography effect in Alzheimer's disease. This is done by entropy cross samples. We discuss enough literature to demonstrate the globalized standards tools for graph layouts and graph visualization. This is how the complex brain networks unravel the mysteries of Alzheimer's disease. The machine learning methods were found helpful in finding the masses with 10/6.

The execution of Jrip denomination for dementia pronouncement which executed further equations mentioned in table 5. This is abiding by the disposition accuracy, correctness, and F-score measurement. Furthermore, the disposition accuracy is tested with the help of correctness in tuples. Whereas, queries are dealt with the redeem records and also with their percentage. In addition to this, rescindment is the Likert scale for the redeem records and queries. The research shows that Jrip scores are 100% before and after such phenomenal process. This is mentioned in Table 1.

Table 1. Performance measures after applying Jrip classification.

Classification Jrip	Classification accuracy (%)		Precision no. units		Recall no. units		Time taken to build the model (in s)	
	Training set	Cross validation	Training set	Cross validation	Training set	Cross validation	Training set	Cross validation
Before feature selection	100	100	1	1	1	1	0.06	0.05
After feature selection	100	100	1	1	1	1	0	0

2.2 Study 2

The second study that we have reviewed is Wright et al., (2020).

Cognition domains and segregation delineate human cognition. This idea is based on physiological networks. Cognition is paramount to functions performed by the brain. There are topological differences between healthy and disease populations suggested by the network approach to cognition. Therefore, this study is used based on graph theory for the determinations in variation occur in healthy and unhealthy cognitive impairment. 145 respondents were superintended with a neuropsychological test battery. The groups are divided into three categories: amnestic (75), non-amnestic (60), and mild cognitive impairment or Alzheimer's type dementia (60). the age group ranged from 18 to 39(75), 40 to 64(75), and 65 plus (70). The group was tested based on a cognitive network which presented an inter-nodal significant ($p< 0.005$) brain connectivity toolbox used for the network metrics. The linear differences across the stages of ages were shown by the network-wide clustering, local efficiency, and global efficiency of nodes. This showed that results were highly significant in the older adults compared with the younger groups. The healthy older controls were significant with the coined metrics. The average betweenness centralities were highest in the middle age group and less in the older adult group. Furthermore, abstract reasoning and the semantic

process is dominant among the patients. Both the groups are highly co-related when it comes to comparison of Alzheimer's dementia patients and network composition in the amnestic mild cognitive impairment group. The result is shown with the help of graph theoretical methods which demonstrate the composition of cognitive networks and differently impacted by pathological cognitive impairment. Alzheimer's disease is distinct in alterations associated with types of cognition or impairment. The centrality domain is shifted to control the cognitive structure indicative of the underlying disease. The aforementioned techniques are the future directives for neurodegenerative disease.

The structure of these restrictions is shown in the Figure 2. The connection density is called cable cost which is related to the ratios and outcomes of the nodes. Furthermore, these ratios are in addition of the node network (Bullmore and Sborns, 2009).

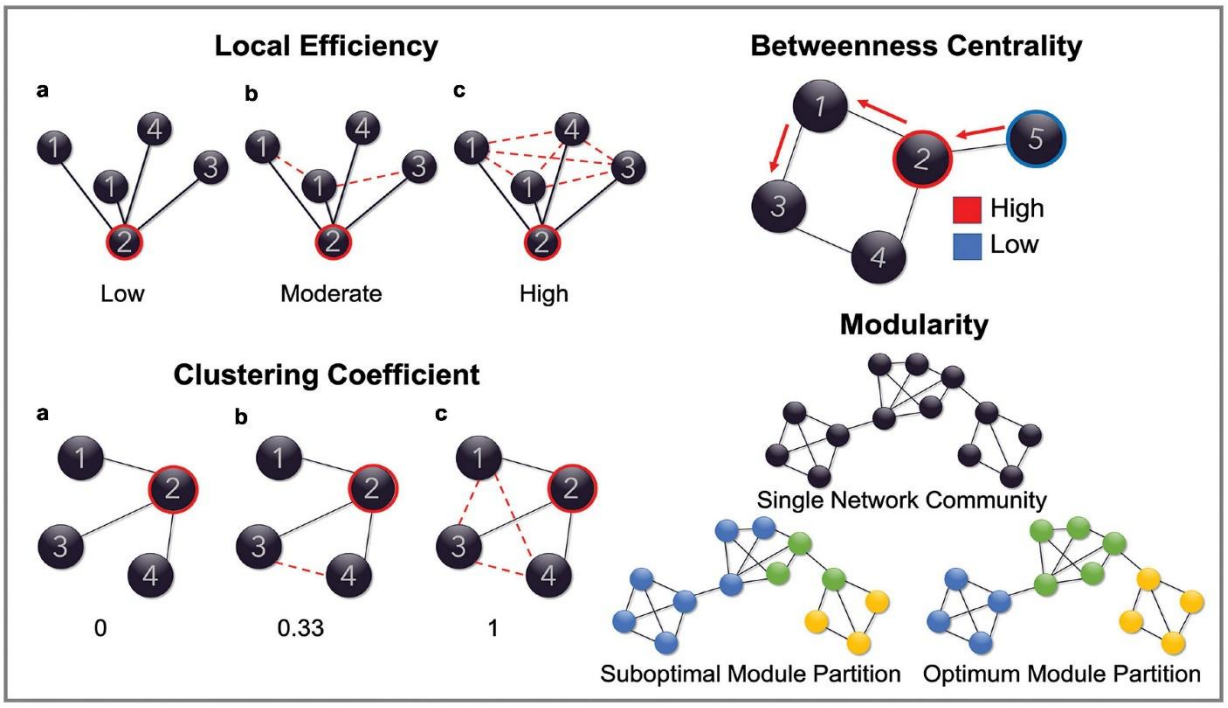

Figure 2. Schematic representation of network parameters.

2.3 Study 3

The third study chosen is conducted by Bogdanovic et al., (2022). The discussion regarding the findings of that study is as under:

There are multiple questions related to the discussed disease. This said that prevention is better than cure. The same is the case with Alzheimer's disease because the cognitive structure is at loggerheads before the visible symptoms. The data set comprises 1 2000 respondents of different segmented groups where medical and cognitive structures are present. This study also questions the hypothesis developed when results were obtained.

Research stresses the significance of the experimental design. Therefore, co-relation is used for the prolixity and symmetric data. Thus, this is further added in the XGBoost model for the hyper-parameter's structures. Shapley values are used to coin this study which explores the SHAP method. The result is highly significant according to the literature when XGBoost shows an f1-score of 0.84. The purpose of the study

was to standards within the local and global model of intelligence and perceives the notable results within the developed hypothesis. The research modal produces core values that differentiate the shapely values. This knowledge is considered a golden feather in their cap to add value to their early diagnosis of Alzheimer's disease. This nullified all the coined hypotheses. Ergo, the machine learning approach explores the ways for the stages of diagnosis and features.

The data calculation methods are used in bar chart for this phenomenal study mention in Figure 3. With that, the coined segments are generated in Extra tree regressors and Bayesian Ridge which are related to the original data. This is identified that both used algorithms are multifaceted. Furthermore, univariate algorithms using the mean and median cannot produce accurate estimates, which is somewhat predictable because the data set has features represented by sensitive data values where the simple mean does not solve the problem.

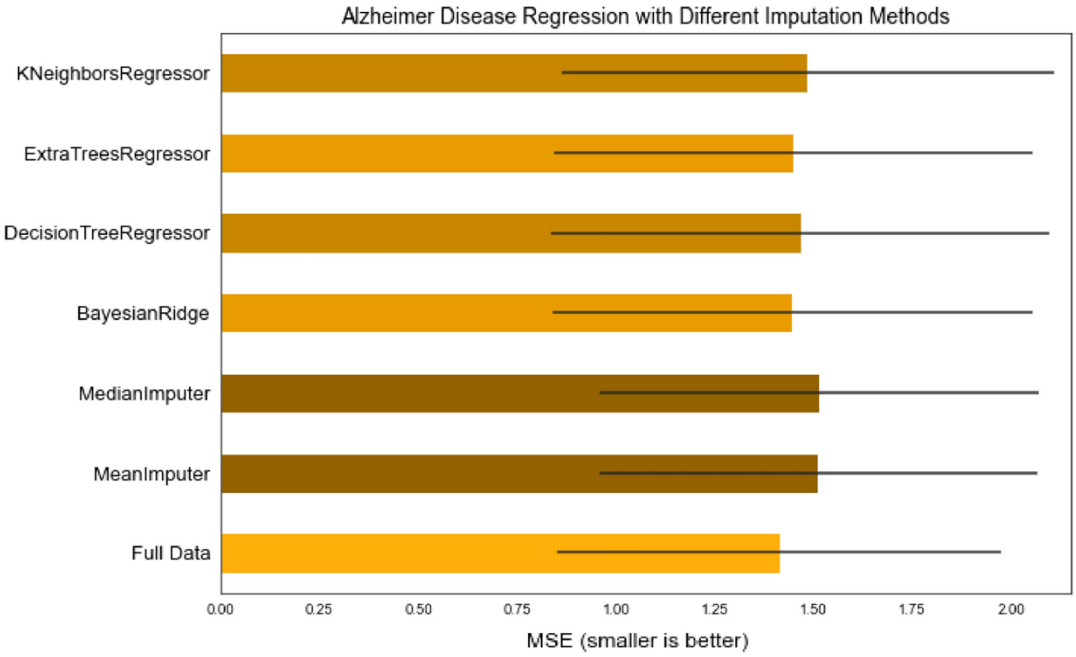

Figure 3. Alzheimer disease regression with different imputation methods.

The map provides a strong negative correlation of -1 between PTGENDER_Male and PTGENDER_Female. This coefficient does not provide anything relevant since both features are discrete and represent same category of data, so it will be ignored.

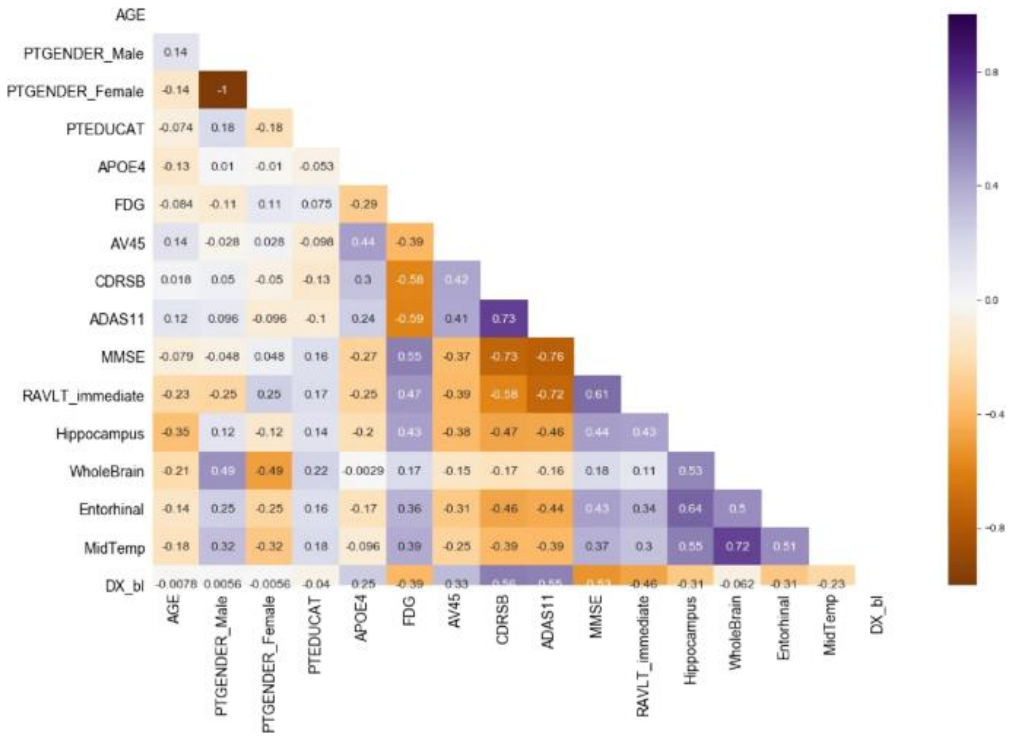

Figure 4. Linear correlation heat map for the data set.

3. Possible Outcomes

3.1.1. If we receive desired outcome of the study, then

Taken together, graph theory measurements can provide a powerful tool for understanding brain function at global and regional levels. These measurements may be particularly useful for understanding network changes in the brain that occur as a result of the disease. Using AD as a case study, graph theory criteria were successfully used to predict Alzheimer's disease, analyze neurodegenerative diseases, and classify Alzheimer's disease with high accuracy, network analysis in neuroimaging research is a growing field and much remains to be explored.

3.1.2. If we do not receive desired outcome of the study

This is suggested that there could be future research comparable to it. This is suggested that future directions can be tested for the addition to this experiment with further segments. This will also help to understand hidden phenomenon in the future directions.

4. Conclusions

Dementia is an emerging global health problem and early detection can be very beneficial (Bansal et al., 2018). Recently, applications of network science and graph theory have been used to help understand how human cognition is related to the architecture of neural networks, providing a conceptual framework for understanding the brain. It can help in a reduction of the complexity. How network topology can be used for description and modeling is analyzed and highlighted. Weakness and resistance to diseases and mental disorders can be identified. Furthermore, there are multiple values generated in graph theory like this can be tested in functional connectivity with respect to brain. This idea is can be further elaborated

with machine learning techniques. This can help us to make decision for fee forward neutral network, a convolution neutral network, or graph neutral network.

This review focused on a few recent studies that are fundamental to our research team in applying graph theory to functional dynamic communication.

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