Coursework assignment:

development and implementation of a Bayesian network

Title: Bayesian network for mild cognitive impairment and the progression to dementia

MSC DATA SCIENCE

DSM100: Artificial Intelligence

FIGURES:

Figure 1: MCI Bayesian Network

Introduction

Mild cognitive impairment (MCI) is a stage of cognition between normal and dementia. Research has shown that up to 60% of those diagnosed with MCI will progress to having dementia within 5 years of the diagnosis. Several risk factors that lead to this progression have been identified. These include, amongst others, APOE4 allele, white matter hyperintensities (WMH) and being an older age female. (Ashwati Vipin, 2023) These three factors form part of a simple Bayesian network to show the probabilities of getting dementia if diagnosed with MCI.

Specification:

The Decision Support System shows the nodes and the causal relationships between two variables in a directed way. Every node has a conditional probability table which represents the probability of all the values for a node given the parents of each. Age was a predetermined factor in the design as the data in the study was limited to people over 55 years of age. The study was also limited to those who were already diagnosed with Mild Cognitive Impairment (MCI). The data is based on a study undertaken between August 2013 and August 2015, at Beihua Hospital Memory Clinic and Department of Neurology in China.

The parent nodes include the Apoe4 allele gene and Female. These two nodes have both been shown to be a cause of MCI. The MCI node is linked to both WMH and Dementia nodes, both are related to MCI and lead to Dementia.

Task: Predict the progression from mild cognitive impairment to dementia with background knowledge based on age, gender, apoe4 gene and WMH values.

Objectives:

1) conceptual description of the network

2) represent the background knowledge as a Bayesian network

3) Implement the network in Python.

Conceptual design:

5 nodes form part of the design.

1. APOE4, values: true and false. APOE4 has a causal relationship to MCI which can lead to Alzheimer disease dementia. Having one copy of the e4 variant of the APOE-e4 gene is related to increased risk of Alzheimer disease, people with 2 copies of this variant are at a higher risk. (Jing Qian, 2017)
2. FEMALE, values: true and false. FEMALE has a causal relationship to MCI. Because females live longer than their male counterparts, they are at higher risk of developing Alzheimer disease. (Andrew E Budson, 2022)
3. MCI, values = true and false. MCI is known to lead to Dementia. MCI is not a type of dementia, but those diagnosed with it are at higher risk of developing dementia. From Age 70, 18% of people with MCI progress to Dementia. (Pan Chen, 2023), (Mild Cognitive Impairment (MCI), n.d.) In general though, around 1 in 4 people progress from MCI to dementia (Andrea M. McGrattan, 2022)
4. WMH, values: normal or high. White matter hyperintensity on the brain due to cerebral small vessel disease is related to the future risk of developing dementia or MCI. It is easily detected on MRI scans. It may be of greater importance than amyloid which has been widely known to be the primary cause of Alzheimer disease. (Adam de Havenon, 2022)
5. DEMENTIA, values: true and false. Because of aging populations, dementia is likely to become an increasing challenge. (Shin, 2022)

Representation of background knowledge as a Bayesian network

Known statistics from research previously completed:

The probability of APOE4 and MCI after 55 years of age is 42%. (Jun Ma, 2022)
The probability of MCI with APOE4 for a female after 55 years of age is 23% and for a male 19%. (Jun Ma, 2022)
The probability of progression from MCI to Dementia is around 1 in 4 people = 25%. (Andrea M. McGrattan, 2022)
The probability of WMH scores being high with those diagnosed with MCI after the age of 55 is 74%. (Jun Ma, 2022)

The Bayesian network with the associated probabilities is represented in Figure 1 below.

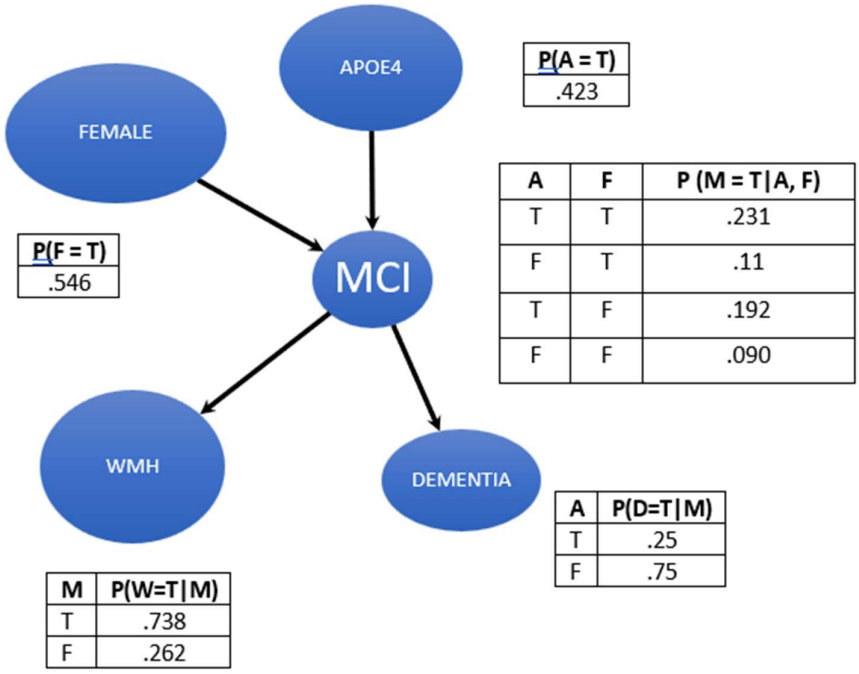

Figure 1: MCI Bayesian Network

Associated Probabilities:

MCI: probabilities for Age, APOE4 and Female:

Mild Cognitive Impairment (MCI) precedes Dementia and is a deficit in episodic memory is the most common symptom. In this network, an age of >55 years was incorporated into both the APOE4 and Gender nodes.

The following statistics about Apoe4, gender and WMH come from (Jun Ma, 2022).

Calculations for the probabilities are shown below.

a. **APOE4 allele gene:**

P (MCI | APOE4 = T, Age 55+ = T) = .423
P (MCI | APOE4 = F, Age 55+ = T) = .198

b. **Female:**

P (MCI | Female = T, Age 55+ = T) = .546
P (MCI | Male = T, Age 55+ = T) = .454

c. APOE4 and Female:

P (MCI | APOE4 = T and Female = T) = .423 x .546 = .231
P (MCI | APOE4 = F and Female = T) = .198 x .546 = .11
P (MCI | APOE4 = T and not Female (i.e. Male) = T) = .423 x .454 = .192
P (MCI | APOE4 = F and not Female (i.e. Male = F) = .198 x .454 = .090

d. WMH:

P (WMH = High, Age 55+|MCI) = .738
P (WMH = Normal, Age 55+|MCI) = .262

e. MCI progression to DEM:

The statistic for the progression from MCI to dementia is taken from research of studies from 647 articles. (Andrea M. McGrattan, 2022)**.**

P (progression from MCI to DEM) = .25
P (no progression MCI to DEM) = .75

Is it a stand-alone system?

This is not a stand-alone system.

Can it be integrated with other systems?

Yes, integration with other systems is possible and recommended. There are many more variables that could be included in the network, these include, amongst others, other tests, for example, the Trial Making Test (TMT), Stroop colour word test, Lawton scale and IQCode score. Levels. Different stages of Bayesian modelling could also be applied to incorporate other data sets. The duration and progression of the diagnosis in terms of cognitive decline and reduced functioning physically could also be incorporated. Incorporation of the level of amyloid protein and neurodegenerative burdens could assist in determining the severity level of the diagnosis. Dementia could also be sub-divided, for example Alzheimer disease, Lewy body Dementia, and Vascular Dementia.

Input data and knowledge:

Input data includes apolipoprotein E4, MRI measures of White matter hyperintensities (WMH) for those with amnestic MCI and those with non-amnestic MCI. Inclusion criteria are those of 55 years of age and older with a MCI diagnosis, but not one of dementia. A dementia rating scale score of 0.5 is also an inclusion of the data, this means that the patient did not meet the DSM-IV criteria for dementia and that they showed no evidence of impairment in the Activities of Daily Living (ADL) test. The data was also subdivided into amnestic (aMCI) and non-amnestic (naMCI) groups. aMCI tends to convert to Alzheimer disease (AD) and naMCI to the other forms of dementia.

The data for this model was further limited to only include the aMCI individuals as the APOE4 alleles are more prominent.

How can the data be obtained?

The data can be obtained from the report available in the BMC Geriatrics journal. The authors can also be contacted directly to obtain the data used in the study. (Yuan Lu, 2021)

What are the outputs?

Outputs include whether a patient has MCI or dementia and what factors influence the diagnosis. Factors of particular interest in this network include female participants, participants with the APOE-e4 gene, those with high WMH levels and those already diagnosed with MCI, but not dementia.

What are the potential risks in the development of such a system?

The system could become quite complex if incorporated into other systems with more variables. Datasets could be unbalanced or insufficient. Oversampling techniques, for example Synthetic Minority Oversampling Technique (SMOTE) may be required. The sample does not include members of all population groups.

Who are potential stakeholders and users of your DSS?

Researchers, Clinicians, and family members will all be able to make use of the decision support system.

Implementation of the Bayesian network: [

The dementia network implementation in Python can be found in the corresponding pdf file.

Querying the Bayesian network:

The following three questions were posed in Python in relation to the dementia network:

Question 1: What is the probability of dementia in females with the APOE4 Allele given MCI?
Answer: 0.3654

Question 2: What is the probability of having high WMH levels in females with the APOe4 gene given MCI?
Answer: 0.6282

Question 3: What is the probability of having high levels of WMH in females who do not have the APOE4 gene, given MCI?
Answer: 0.6468

Question 4: What is the probability of dementia in males with APOE4 gene who are diagnosed with MCI?
Answer: 0.3050

Conclusion

The Bayesian network shows that those people diagnosed with MCI and who are carriers of the APOE4 gene will have a higher probability of higher levels of WMH, this in turn will impact memory and therefore more likely to lead to dementia. MCI affects those who are of older age and there is a high chance of MCI progressing to dementia. Because females are known to live longer, they are more at risk of this progression. Effectively diagnosing MCI before its progression to dementia is therefore an important area of research. Bayesian networks have been found to be highly effective in this diagnosis.

Bibliography

Adam de Havenon, K. N. (2022). White matter hyperintensity progression is associated with incident probable dementia or mild cognitive impairment. *SVN Stroke and Vascular Neurology, 7*(4). doi:10.1136/svn-2021-001357

Alzheimer's Society. (n.d.). Retrieved from https://www.alzheimers.org.uk/about-dementia/types-dementia/mild-cognitive-impairment-mci

Andrea M. McGrattan, c. a.-M. (2022, March 13). *National Library of Medicine, National Centre for Biotechnology Information*. doi:10.1002/trc2.12267

Andrew E Budson, M. (2022, January 20). *Harvard Health Publishing, Harvard Medical School*. Retrieved from https://www.health.harvard.edu/blog/why-are-women-more-likely-to-develop-alzheimers-disease-202201202672#:~:text=You%20are%20more%20likely%20to%20develop%20Alzheimer%27s%20disease,women%20have%20stronger%20immune%20systems%20compared%20to%20men.

Ashwati Vipin, D. K. (2023, June 03). APOE4 carrier status determines association between white matter disease and grey matter atrophy in early-stage dementia. *Altzheimer's Research & Therapy, 15*. doi:https://doi.org/10.1186/s13195-023-01251-4

Jing Qian, F. J. (2017, March 21). APOE-related risk of mild cognitive impairment and dementia for prevention trials: an analysis of four cohorts. *PLOS Medicine*. doi:https://doi.org/10.1371/journal.pmed.1002254

Jun Ma, L.-Y. M. (2022). Association of Homocysteine Levels with Medial Temporal Lobe Atrophy Among Carriers and Non-carriers of APOEe4 in MCI Subjects. *Frontiers Psychiatry, 13:823605*, unknown. doi:https://www.frontiersin.org/articles/10.3389/fpsyt.2022.823605/full

Pan Chen, H. C.-L.-T. (2023). Global prevalence of mild cognitive impairment among older adults living in nursing homes: a meta-analysis and systematic review of epidemiological surveys. *Translational Psychiatry, 13*(88). doi:https://doi.org/10.1038/s41398-023-02361-1

Shin, J.-H. (2022, April). *Dementia Epidemiology Fact Sheet 2022*. Retrieved from National Library of Medicine, National Centre for Biotechnology Information: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9081392/

Yuan Lu, C. L. (2021). Prevalence of mild cognitive impairment in community-dwelling Chinese populations aged over 55 years: a meta-analysis and systematic review. *BMC Geriatrics, 21*(10). doi:10.1186/s12877-020-01948-3