AI Assignment 1: Representing and Reasoning with Postgraduate Supervisor Selection using Bayesian Graphical Models

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1 INTRODUCTION

1.1 Background

This project aimed to develop a Bayesian Network model based on expert knowledge and/or data collection and analysis to benefit the decision processes of some community of users.

A Bayesian Network, in its most basic form, functions as a Directed Graph (DG) where nodes and arcs represent the random variables of a given dataset and the casual relationships between them respectively. Nodes with no incoming arcs contain prior probability tables (or belief tables) whereas remaining nodes contain a separate conditional probability table (CPT). These tables catalogue the probabilities of the occurrence of a node state (which are dependant on the outcomes of parent nodes in the case of CPT's). These probabilities are calculated using Bayes' theorem as its basis:

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)} \tag{1}$$

Bayes theorem is a mathematical function which predicts the probability of an event A occurring on the condition that an event B occurred. To illustrate this, the example of three variables in a Bayesian Network that all have the possibility of being true or false is used: Grass is wet, it is raining, and the sprinkler system is on. *Raining* and *Sprinkler system is on* are parent nodes to *Grass is wet* as they have the potential to affect the probability of it being true or false, depending on their own values. This implies that *Grass is wet* will have a conditional probability table cataloguing its own probability of being wet, depending on these parent variable values. *Inference* is performed when a Bayesian Network predicts the outcome of a certain variable using the conditional probabilities of all nodes which have an effect on it.

1.2 Objective

It was decided to develop a Bayesian Network that would be used as a tool for Computer Science postgraduate students to best select a supervisor for their Masters studies. The tool will be used to determine which supervisor is best suited to a particular Masters applicant using an analysis of the student's research proposal as evidence. This tool will increase an applicant's awareness of supervisor options and their understanding of which supervisor is best suited to their research. This will streamline the application process and likely improve student-supervisor collaboration.

Evidence will be supplied in the form of a student's research proposal, reduced to a summary of topic interests and sub-topic focuses. The Bayesian Network will then use the student's prominent research areas to determine the best-suited supervisor.

1.3 Potential user community

The main user community for this network is postgraduate students who are applying for their Computer Science Masters at UCT and are unsure of which supervisor is best suited to them. To create a network with higher levels of predictive accuracy, however, the scope of this system was limited to applicants wishing to pursue a Masters in an AI/Machine Learning field. The popularity of AI-focused research indicates that this network likely will cater to a large number of applicants, whilst maintaining a smaller network with higher predictive accuracy.

2 PROBLEM ANALYSIS

2.1 Postgraduate application process

Masters degrees at UCT can be completed either by dissertation alone or by coursework and a minor dissertation [2]. Students seeking to do a Masters by dissertation are required to speak to a prospective supervisor before applying. The application process, for either type of Masters, includes the student submitting a research outline and motivation [1]. Complications arise when some lecturers either do not supervise or do not take on new research, such as Dr Matt Jones and Professor Edwin Blake respectively [4]. Thus, although a topic may be taught at UCT, this does not guarantee that research or supervision in that topic is supported by UCT. This leads to challenges when students need to select a supervisor to approach for postgraduate research, especially if they are not already a UCT student with prior knowledge of the supervisors available.

2.2 Research interests

2.2.1 Research interests of potential incoming UCT Masters students. This project investigated the research interests of Computer Science students. Our informal investigation was conducted verbally and revealed that the majority of students in the UCT Computer Science Honours class have future research interests in the field of Artificial Intelligence (AI). Students typically are interested in fields of which they have heard. We thus used classifications of AI sub-fields as taken from the introductory lecture notes [7] for the AI course offered to the UCT Computer Science Honours class.

2.2.2 Research interests of supervisors at UCT. The research interests of staff in the Department of Computer Science at UCT are listed on the CS staff website [4]. Some difference existed between advertised or stated research interests (those given on the website) and current or recent research interests and efforts. To inform our Bayesian network of the latter, we referred to the UCT Computer Science Research Document archive [5] for recent papers related to AI that were supervised by lecturers Deshen Moodley, Thomas Meyer, Hussein Suleman, Maria Keet or Geoff Nitschke. We collected the abstracts of the five most recent papers for each aforementioned supervisor. These abstracts were then fed to a Java program for processing. The program analysed and classified their contents, for casefile generation purposes. Details regarding the

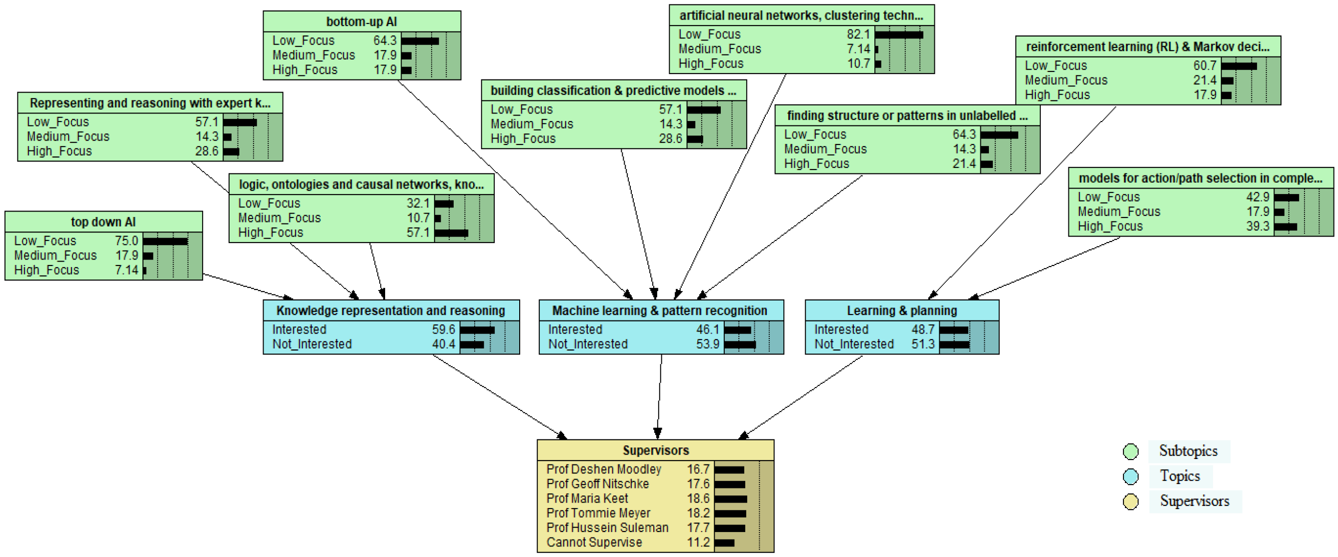

Figure 1: Diagram of Final Bayesian Network graphical model constructed in Netica

casefile (e.g. its generation, contents and purpose) are further discussed in Section 4.

3 DECISION NETWORK MODEL

A Bayesian network graphical structure was designed to represent and reason with the problem of choosing a suitable supervisor for postgraduate research (Figure 1).

3.1 Domain Variable Selection

Examination of the problem revealed the main variables of interest forming the basis of our network's structure. These variables were broadly classified into three categories: topics, sub-topics and supervisors.

3.1.1 Topics. A topic represents a significant theme forming part of a more general research area. Given that the scope of this tool is limited to students wishing to pursue AI research, a topic represents a major field within this discipline. Using the classification scheme of AI fields described in Section 2.2.1, AI was deconstructed into three main topics: *Knowledge representation and Reasoning*, *Machine Learning & Pattern Recognition*, and *Learning & Planning*. These main topics were deemed to sufficiently cover the fields of AI research which are currently in the research interest of UCT's Department of Computer Science. Students wishing to take part in AI research within the department can be either interested or not interested in an AI topic.

3.1.2 Sub-topics. Drawing further from the classification scheme in Section 2.2.1, AI topics were deconstructed into sub-topics. *Knowledge Representation and Reasoning* was broken down into "Top-Down AI", "Representing and Reasoning with Expert Knowledge", and "Logic, Ontologies and Causal Networks, Knowledge Based systems". Similarly, *Machine Learning & Pattern Recognition* was broken down into "Bottom-Up AI", "Building Classification & Predictive Models from Labelled Historical Data", "Finding Structure or Patterns in Unlabelled Data", and "Artificial Neural Networks, Clustering Techniques". Finally, *Learning & Planning* was broken down into "Models for Action/Path Selection in Complex Environments" and "Reinforcement Learning (RL) & Markov Decision Processes". Student research proposals in the domain of AI submitted to the Computer Science department will contain varying levels of focus on any number of these sub-topics. Levels of focus on a sub-topic will be classified as either Low, Medium or High.

3.1.3 Supervisors. The final variable needed to represent our problem is supervisors. A supervisor is a faculty member of the Department of Computer Science who is able to oversee a student's research into an AI topic. Supervisors in UCT's Computer Science department were identified based on an alignment of their research interests (as declared on the Computer Science Department's website) with the AI topics and sub-topics specified above. The set of supervisors in the department considered relevant to our problem is composed of the following faculty members: Associate Professor Deshen Moodley, Dr Geoff Nitschke, Associate Professor Maria Keet, Professor Tommie Meyer, and Associate Professor Hussein Suleman. In addition to these members, the "Cannot Supervise" state was added to the Supervisor node to signify instances where supervision is impractical.

3.2 Causal Relationships

The qualitative relationships between variables in the Bayesian Network are represented by a set of directed arcs, representing direct dependencies between variables of interest. For a given topic and its set of associated sub-topics, it is believed that the degree of student proposal focus in a sub-topic within AI reasonably estimates their level of interest in a more general AI topic (Figure 2(a)). For a given set of topics, it is believed that a student's level of interest

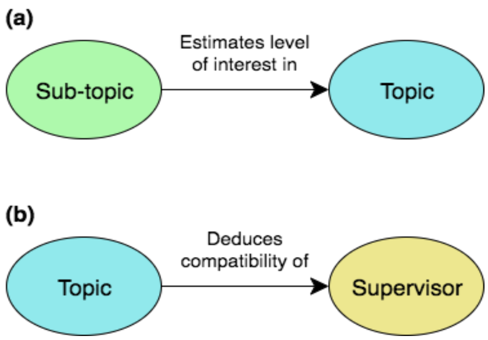

Figure 2: Graphical representation of causal relationships between domain variable types

in these topics can determine which supervisors a student is most compatible with for their research. In this sense, a topic can to deduce the compatibility of a supervisor with a student's estimated interests within the field of AI (Figure 2(b)).

4 TRAINING DATA

The Bayesian Network was trained using a casefile to generate the prior and conditional probabilities seen in Figure 1. Abstracts from research papers published by UCT AI lecturers were used to generate sup-topic keyword groupings. Postgraduate student research papers supervised by those same lecturers were used in addition to the keyword groupings to generate the casefile. Keyword analysis was conducted in Excel and the classification of student papers and the generation of the casefile was performed by a Java program.

4.1 Keyword Grouping

Published papers authored by UCT lecturers were used to establish keywords relating to sup-topics in AI. The abstracts of the 10 most recently published papers of each of the 5 lecturers (listed as states in the Supervisor node in Figure 1) were collected for analysis. In total 1834 distinct words from these 50 abstracts were collected and analysed. The frequency of each of the distinct words present in the abstracts was recorded. Common English words (such as "the", "and", "for") were then removed from the set so that only 1545 technical terms remained. The 100 most frequently used technical terms were then used to generate keyword groups. To reduce overlap between sup-topics and produce specific keyword groupings, each word was assigned to one AI sub-topic only. Each word was manually assigned to a group based on current knowledge of the AI sub-topic and a general understanding of the technical term. For example, "ontology" was assigned to the "Logic, Ontologies and Causal Networks" sub-topic keyword group and "Neural" was assigned to the "Artificial Neural Networks" keyword group.

Instead of entire papers, only the abstracts of the papers were analysed. An abstract represents the entirety of a body of research and thus would accurately represent any and all CS topics covered by using only necessary terminology. An entire paper may cover other topics through the background and discussion sections, thereby increasing the number of keywords (less related to AI) to classify. The assumption was made that if a word was not mentioned in an abstract, it is likely that the word was not key.

Sub-Topic	Word Count	Proportion	Classification
Top Down AI	0	0%	Low
Logic, ontologies ...	7	28%	High
...			
Markov decision ...	4	12%	Medium

Table 1: An example classification of sub-topic focuses used in the casefile

4.2 Casefile Generation

Each row of the casefile represents the classification of one student research paper. Papers, relating to AI, supervised by each relevant lecturer in the past 3 years were collected. Each row of the casefile included the lecturer which supervised the research, a High, Medium or Low focus rating for each of the sub-topics, and an Interested or Not Interested classification for each of the main AI topics. As 24 student papers were collected, the casefile contained 24 rows encoding the focus and interests of each paper.

4.2.1 Determination of Student Paper Focus. Each word in the abstract of each student paper was analysed - if the word was contained in one of the AI sub-topic keyword groups, then the count of that associated keyword group was incremented. For example, if the keywords `["grammar", "owl", "reasoning", "neural"]` were extracted from the student abstract, the following counts would be produced: [logic, ontologies and causal networks: 2, Representing and reasoning with expert knowledge: 1, artificial neural networks, clustering techniques: 1]. Using these counts, the proportion of keyword groups could be calculated relative to the number of AI words present in the abstract; continuing the example, the proportion of sup-topic groups would be [logic, ontologies and causal networks: 50%, Representing and reasoning with expert knowledge: 25%, artificial neural networks, clustering techniques: 25%].

Using the proportions of sub-topic groupings across all abstracts, the percentage boundaries of the High, Medium, Low focus classification bins were set. The average sub-topic proportion was 13% (on average, the number of words relating to a specific sub-topic formed 13% of the AI words present in an abstract). The upper-quartile of sub-topic proportions was 20% (a quarter of the sub-topic proportions calculated were greater than 20%). Using these as a guide, if the proportion of a sub-topic was less than 13%, it was classified as "Low Focus", if the proportion lay between 13% and 20%, the sub-topic was classified as "Medium Focus", and if the proportion of words related to a specific sub-topic was greater than 20%, then that sub-topic was classified as "High Focus". See Table 1 as an example classification of sub-topic focuses in a student abstract.

4.2.2 Determination of Student Paper Interest. Using the causal relationships outlined in Section 3.2, the main topic interests of the student paper were classified. If any of the sub-topics were classified as "High Focus" then the topic it affects would be classified as "Interested" (and "Not Interested" otherwise). For example, if the "Reinforcement Learning" and "Finding Structure…" sub-topics were both classified as "High Focus" in the student abstract, then the paper would further be classified as "Interested" in both Learning & Planning and Machine Learning topics, and "Not Interested" in Knowledge Representation & Reasoning (see Figure 1). In cases where no sub-topic is classified as highly-focused, to ensure that every paper is "Interested" in at least one topic, the single "Interested" topic would be the one affected by the sub-topic with the greatest keyword proportion.

4.3 Limitations

The casefile contains human bias as the keywords assigned to each sub-topic grouping were (although determined by lecturer usage) assigned naively by students with limited AI knowledge. Similarly, it is more accurate to assume that a keyword ("algorithm" for example) may belong to multiple sub-topic keyword groups, not just one. Finding enough lecturer and student papers in AI to generate reliable results, representative of student interests, was infeasible in the project time-frame.

5 MODEL TESTING AND EVALUATION

When assessing the model, two questions were worth asking. The first considers the utility of the model to users, and the second, the veracity of the model (how accurately it models the domain in question).

5.1 Usefulness

5.1.1 Use Cases. As an initial indicator of the usefulness of the network, consider the following two user stories:

User Story 1. *As a student interested in artificial intelligence and applying to study a Masters in Computer Science at UCT, I want to know who I should approach to supervise me for my thesis.*

User Story 2. *As a student interested in artificial intelligence and applying to study a Masters in Computer Science at UCT, I already know which staff member I would like to supervise me, but am uncertain what their specific research interests are.*

For both these user stories, the developed Bayesian network can be of use: in the first via *predictive* reasoning, in the second via *diagnostic* reasoning. To turn the user stories into use cases we considered a specific set of interests or a particular staff member.

Consider User Story 1. A potential Masters applicant could specify focuses in a subset of sub-topics and interests in topics and get an answer as to which supervisor to approach, with the proviso that interest in topics overrides the degree of focus in sub-topics, due to the structure of the network and the Markov property. Within this both positive (active interest), and negative (active disinterest - in the case of the sub-topic nodes by specifying low focus) information can be provided. As a concrete use case, consider someone with the interest profile given in Table 2. Then entering these interests as evidence, the network predicted that the student should approach Professor Moodley, (with a posterior probability of 25%, the maximum for the categorization node).

In the case of User Story 2, the process is simpler - a potential Masters applicant need only enter their potential supervisor. As an example, consider that the potential Masters applicant has determined that due to previous experience with the supervisor, they would like to work with Professor Meyer. By entering Professor Meyer as evidence in the categorization node, they thereby specify this interest.

Sub-Topic/Topic	Interest
Knowledge Rep. and Reasoning	Not interested
Reinforcement Learning & MDPs	Medium Focus
Neural Networks	High Focus

Table 2: An example of an interest and focus profile

After entering evidence there could be two changes in posterior probabilities - both at the topic level, and the sub-topic level. At the topic level, the posterior probabilities indicate a 73.3% chance of interest in Knowledge Representation and Reasoning, and a roughly 60% chance of disinterest in Machine Learning and Pattern Recognition as well as Learning and Planning. At the sub-topic level, the most notable change is a jump from a 57.1% prior probability of high-focus in logic, ontologies, causal networks, and knowledge based systems, to a 62.2% posterior. So the potential applicant may conclude that Professor Meyer is primarily interested in Knowledge Representation and Reasoning, and in particular logic, ontologies, causal networks and knowledge-based systems. They can then draft their research proposal with this in mind. It should be noted that, generally, the sub-topic posteriors do not see major changes upon entering the categorization node as evidence. It is thus recommended that potential users primarily use the table for determination of topic interest, and when determining sub-topic interest, only look at the nodes that see the most changes.

5.1.2 Poll conducted by Honours students. As an empirical way to determine potential interest in the network, a short survey consisting of two questions was conducted on Google forms. The form was posted on the Honours Whatsapp group, where 11 members of the class completed it. Given that many Honours students will be applying for a Masters, it may be expected that those who completed the form were close in profile to potential users of the network. The two questions were:

Question 1. *Suppose you are planning to study a Masters degree in Computer Science at UCT. Would you find a tool that lets you enter your research interests and outputs the best supervisor for you, based on these interests, useful?*

Question 2. *If you were applying for a university that you hadn't studied at previously and that university had such a tool, would you find it useful?*

Figure 3 summarizes the responses to the survey. It can be seen that 8 out of 11 or roughly 72% of respondents agreed that they would find the network useful in the context of applying to a Masters at UCT. 100% of respondents agreed that they would find the network useful in the context of applying to a university at which they had not studied previously. The difference in responses may be explained by the observation that for those who have some post-graduate study at UCT, having been more involved in the

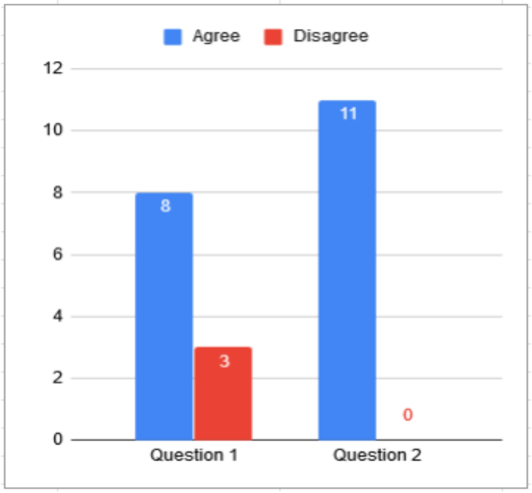

Figure 3: Responses to the survey

Sub-Topic/Topic	Interest
Machine Learning and Pattern Recognition	Interested
Logic, Ontologies and Causal Networks	Medium Focus
Neural Networks	Medium Focus
Reinforcement Learning MDPs	Medium Focus

Table 3: Masters Student Interest Profile

department, some of the information encoded in the network may already be known to students.

The results of the survey indicate that the purpose for which the network was conceived is seen as useful by current honours students, although it may be of most use to students looking to apply to a Masters in Computer Science from outside UCT. A limitation of the survey is that it did not specify the scope of the tool to supervisors involved in AI. Given the popularity of research in AI, however, it might be expected that many students would be interested in research in AI, in which case the tool would still be of use to them.

5.2 Accuracy

5.2.1 Testing against current Masters Students. The ideal case for testing the network would be to see whether it can predict current or previous Masters students' supervisors based on their research interests. Due to time limitations, only a single Masters student was approached to poll him for his interests and current supervisor. The methodology consisted of presenting him with a list of topics and sub-topics, and asking him to specify which of them he was focused and interested in respectively. As levels of focus were not indicated, it was decided for sub-topics that an average medium focus was appropriate. This resulted in the interest profile shown in Table 3.

Based on this interest profile the network predicted that Assoc. Professor Suleman would most likely be his supervisor (posterior 22.5%). His actual supervisor is Assoc. Professor Moodley. This was the network's second most likely choice for supervisor (posterior 19.1%).

Supervisor	Prediction
Professor Meyer	Correct
Assoc. Professor Moodley	Correct
Assoc. Professor Keet	Within one
Dr. Nitschke	Within one
Assoc. Professor Suleman	Incorrect

Table 4: Honours Abstract Test Results

5.2.2 Testing Against Honours Abstracts. Initially, the plan was to divide the training data into both training and testing sets, and for the test set determine whether the network could accurately predict the supervisor of the paper, where the interest profile of the student for the paper would be determined as in section 4.2. However due to the limited size of the data (24 abstracts), and the difficulty in sourcing Masters papers, it was decided that it would be better to rather use all of the data for training. As a result, for testing it was decided to rather use Honours paper abstracts, and see whether the network could predict the supervisor. This was not a perfect metric for testing, but given that potential users of the tools will be coming from an Honours background, it is likely that their current research interests will be based on their previous research in an Honours context, so the metric is still of some use.

Five honours final papers were gathered from the UCT CS Honours project archive [3], one for each supervisor. The papers were gathered from 2018, except for Professor Keet who did not supervise in that year. The interest profile for each abstract was generated using the same methodology as in section 4.2. Table 4 presents the performance of the network against the five abstracts. It can be seen that the network accurately predicted the supervisor in two of the cases, had the actual supervisor as the second most likely choice in another two of the cases, and failed to meet either of these metrics for a single case. Viewed in conjunction with the results of the test against the Masters student's interest profile, the results here provide some indication that the model is generally accurate within a single margin of error; that is, the correct supervisor will be within the set of the predicted two most likely supervisors. As staff members have overlapping research interests, in many cases it is perhaps likely that there is more than one 'correct' choice of supervisor for a student, so this is perhaps not surprising. An implication for potential users of the model is that they should consider approaching not only the most likely predicted choice of supervisor, but also the second most likely.

6 CONCLUSION

Since the introduction of the term AI in 1956, it has been a popular topic that most Computer Scientists have some form of interest in. This is apparent at UCT with supervisors like Associate Professor Moodley being overwhelmed by applications for supervision and only being able to accept exceptional students whose interests align with his own [6]. This paper explored the efficacy of a Bayesian Network that postgraduate students can use to determine which supervisor would be best suited for them based on which topics in

AI they are interested in, or which topics they should focus on in their Master's proposals if they would like to be supervised by a specific staff member.

The network was trained using a casefile created using analysis of two data sources: by obtaining keywords from the abstracts of the 10 most recent publications of each of the supervisors (Professor Meyer, Associate Professor Moodley, Associate Professor Keet, Dr. Nitschke and Associate Professor Suleman), and by analysing the abstracts of the five most recent Master's papers supervised by each of the above listed staff members. Testing of the network showed variable results. In some cases, the network accurately predicted the correct supervisor based on the research interests but in others, it was incorrect. Some supervisors have very similar interests so there is a possibility that students being supervised by one staff member now, could have potentially been supervised by a different one. The variable results were likely a result of the limited training data provided to the BN and the human bias present in the classification of papers which generate the casefile. Some words present in abstracts could easily be classified in several topics. Furthermore, certain keywords would have different meanings if they were grouped together as opposed to being considered as a singularity.

A survey done amongst Honour's students at UCT showed there is an interest for this network, especially for students who are not based at UCT who would not have a sound understanding of supervisor's interests.

However, there are limitations to this network that need to be considered before students use it as an accurate representation of which supervisor to choose. Moving forward, further analysis of past student's papers and supervisor's papers needs to be done to train the network further. To create a more accurate network, other factors which affect supervisor suitability need to be explored such as: the willingness of a supervisor to support remote students, the availability of supervisors to take on new students, and the availability of funding. This network could be further extended to cover more specific and varied fields which would, in turn, represent all the CS research possibilities available at UCT.

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