

## **Summer projects in the Research School of Engineering:**

### **1. Atomically thin nano-materials and devices**

Supervisor: Yuerui Lu [[yuerui.lu@anu.edu.au](mailto:yuerui.lu@anu.edu.au)]

Two-dimensional (2D) nano-materials, such as molybdenum disulfide (MoS<sub>2</sub>) and graphene, have atomic or molecular thickness, exhibiting promising applications in nano-electro-mechanical systems. Graphene is a one-atom thick carbon sheet, with atoms arranged in a regular hexagonal pattern. Molybdenum disulfide (MoS<sub>2</sub>) belongs to transition metal dichalcogenides (TMD) semiconductor family YX<sub>2</sub> (Y=Mo, W; X=S, Se, Te), with a layered structure. These 2D nano-materials can be integrated into nano-electro-mechanical systems, enabling ultra-sensitive mechanical mass sensors, with single molecule or even single atom sensitivities. Moreover, the mechanical resonators based on these 2D nano-materials would be a perfect platform to investigate quantum mechanics, opto-mechanics, material internal friction force, nonlinear physics, etc.

### **2. Nano Biomedical Devices**

Supervisor: Yuerui Lu [[yuerui.lu@anu.edu.au](mailto:yuerui.lu@anu.edu.au)]

The ability to detect bio-molecule at ultra-low concentrations (e.g. atto-molar) will enable the possibility of detecting diseases earlier than ever before. A critical challenge for any new bio-sensing technology is to optimize two metrics --- shorter analysis time, and higher concentration sensitivity in clinically relevant small volumes. Moreover, practical considerations are equally important: simplicity of use, mass producible (low cost), and ease of integration within the clinical structure. Compared with other methods, nano-electro-mechanical system (NEMS) based bio-sensors are promising in clinical diagnostics because of their extremely high mass sensitivity, fast response time and the capability of integration on chip. We have demonstrated a low concentration DNA (atto-molar sensitivity) optically interrogated ultrasonic mechanical mass sensor, which has ordered nanowire (NW) array on top of a bilayer membrane. This method represents a mass-based platform technology that can sense molecules at low concentrations, which could be useful for early-stage disease detection. We can develop this sensor further to measure an array of biomarkers (e.g. DNA or proteins), by providing both the needed specificity and sensitivity in physiological disease (e.g. cancer) detection.

### **3. Synchronization control of oscillator networks with dynamic and adaptive coupling**

Supervisor: Zhiyong Sun and Brad Yu [[zhiyong.sun@anu.edu.au](mailto:zhiyong.sun@anu.edu.au); [brad.yu@anu.edu.au](mailto:brad.yu@anu.edu.au)]

The synchronization behaviour and synchronization control for coupled oscillator networks is a fascinating subject which has found applications in many areas including physics, engineering and social network study. The emergence of synchronization is usually caused by diffusive coupling between individual oscillators, in which the coupling strength and the underlying network topology play important roles. In this project we intend to investigate whether dynamic coupling instead of static coupling could enhance network synchronization. We also aim to incorporate feedback mechanism from a control point of view to design optimal coupling terms as well as network topologies to manipulate synchronization behaviour. Real-life oscillator network models (such as

power networks) may be involved in explaining the results obtained in this project. The supervision process will include a PhD student (Qingchen Liu) working on multi-agent systems and synchronization control. The goal of this project is to present a research report and paper.

*Requirements/Prerequisites:*

- Applicants should have relevant background on control theory, differential equation and programming skills (Matlab etc.)

*Students will gain:*

- Experience in working on research problems in the area of networked oscillator and synchronization, and applying the control/optimization theory to solve them.
- Skills in preparing and writing research reports and papers to summarize the outcomes.
- Be a part of a leading research school and team.

*Background Literature:*

- F. Dörfler and B. Francesco. "Synchronization in complex networks of phase oscillators: A survey." *Automatica* 50, 6 (2014): 1539-1564

#### **4. Formation control of constant-speed agents (UAVs) with wind effect**

Supervisor: Zhiyong Sun and Brad Yu [[zhiyong.sun@anu.edu.au](mailto:zhiyong.sun@anu.edu.au); [brad.yu@anu.edu.au](mailto:brad.yu@anu.edu.au)]

Constant-speed agents may refer to ground vehicles or flying vehicles with constant-speed constraints in operation. On occasions the flying vehicles used in the control task (e.g. Aerosonde UAVs or other types of fixed wing aircrafts) usually fly most efficiently at fixed, nominal speeds. We aim to study how perturbations such as wind or air flows affect the performance and stability of a group of such agents working in a cooperative team. A further topic may involve estimation technique for individual agent to estimate (wind or flow) parameters and to compensate the effects caused by perturbations in order to improve the controller performance. The supervision process will include a PhD student working on multi-agent systems and formation control problems. The goal of this project is to present a research report and paper.

*Requirements/Prerequisites:*

- Applicants should have a background in control theory and programming skills (Matlab etc.)

*Students will gain:*

- Experience in working on research problems in the area of multi-agent systems, and applying the control theory to solve them.
- Skills in preparing and writing research reports and papers.
- Be a part of a leading research school and team.

## 5. Sound signal correlation: Modelling and measurement in a reverberant enclosure

Supervisor: Thushara Abhayapala [[Thushara.Abhayapala@anu.edu.au](mailto:Thushara.Abhayapala@anu.edu.au)]

In application such as spatial sound reproduction and control, it is necessary to adopt the signals from secondary sound sources (loudspeakers) depending on the signal level at error microphones which are away from the listener's ears. It is important to know the signal correlation between error microphones and listener's ear. The project involves modelling of signal correlation in reverberant room, undertake a measurements using a dummy head (Kemar mannequin: <http://kemar.us>) and analyse the data to build a realistic signal correlation model.

*Requirements/Prerequisites:*

- Basics of signal processing, Matlab, mathematical & analytical skills, comfortable with using a computer, loudspeakers, amplifiers etc. to conduct experiments, common sense, ability to work with a team, willing to learn.

## 6. Sampling of 3D wave-fields using first order directional sensors

Supervisor: Thushara Abhayapala [[Thushara.Abhayapala@anu.edu.au](mailto:Thushara.Abhayapala@anu.edu.au)]

Shannon sampling theorem is well known. Generalised sampling for one dimensional signals (e.g., time signals) includes gradient sampling – i.e., at each sampling point includes the signal value as well as its gradient. When you include gradients of the signal at the sampling point, the sampling time could be increased. This concept has been extended to 2D signals. The aim of this project is to extend these results to 3D wave fields which are due to propagating signals. We have some preliminary results from a recently concluded project but these results needs to be verified and extended. Also, we would like to develop sampling grid on a sphere for first order derivative sampling which is equivalent to having directional sensors.

## 7. Forecasting electricity demand at the household level: training forecasting models with smart meter data

Supervisor: Marnie Shaw [[Marnie.Shaw@anu.edu.au](mailto:Marnie.Shaw@anu.edu.au)]

Traditionally, monitoring of electricity demand has been carried out based on aggregated electricity load of many consumers. With the transition to integrate renewable energy sources into the grid, it is now important to monitor and even predict the energy flows at the individual household level. This is a difficult problem because household loads are highly variable, nonlinear and influenced by a large number of factors (e.g. weather, size of household, holidays, household activities). The use of smart meters provides us with an opportunity to develop and train accurate forecast models.

## 8. Using neural networks to develop an improved measure of 'brain age'

Supervisor: Marnie Shaw [[Marnie.Shaw@anu.edu.au](mailto:Marnie.Shaw@anu.edu.au)]

Recently, brain images (e.g. Magnetic Resonance Images) have been used to predict biological age. This works reasonably well in younger adults, but older adults show large variability in structural

brain changes such that current models aren't accurate (mean error of prediction 5 years - Cole et al., Nature 2016). This project will use machine learning to identify relationships between imaging variables, as well as health measures and demographics, for a better prediction of biological brain age in older adults.

## **9. Integrating renewable energy sources (energy sharing between microgrids)**

Supervisor: Chathurika Mediwaththe [[Chathurika.Mediawaththe@anu.edu.au](mailto:Chathurika.Mediawaththe@anu.edu.au)]

Small-scale demand-side management as in residential gated communities (e.g. a retirement village) has received attention with the increasing popularity and cost reductions of household-distributed renewable power generation and storage technologies. Community energy storages (CES) can be integrated with novel small-scale demand-side management approaches to efficiently utilize onsite energy generation from consumer-owned renewable power resources such as rooftop photovoltaic (PV) systems. Prior research has considered decentralised energy trading systems with the use of CESs to regulate peak electricity demand of residential neighbourhood area networks [Mediwaththe et al. 2016a, Mediwaththe et al. 2016b]. Moreover, cooperative frameworks have been used to investigate energy exchange among geographically dispersed microgrids to reduce power distribution losses [Saad et al., 2012]. Having insights from these works, it would be interesting to investigate cooperative energy exchange among multiple energy trading systems, similar to the systems studied in [Mediwaththe et al. 2016a, Mediwaththe et al. 2016b], where one system with net surplus PV energy can trade energy to another system with net energy deficit rather than directly selling energy to the grid. Such frameworks would enhance demand-side management as users in the energy trading systems can consume energy traded by nearby systems without relying on the main power grid. This would result in better utilisation of CES energy storage devices dispersed across a vast geographic range for effective demand-side management.

## Summer projects in the Research School of Computer Science:

### **1. Charging Multiple Sensors Simultaneously with Wireless Energy Transfers via Mobile Chargers**

Supervisor: Weifa Liang [[wliang@cs.anu.edu.au](mailto:wliang@cs.anu.edu.au)]

Wireless Sensor Networks (WSNs) now become critical components in IoTs from environmental monitoring to civil surveillance. However, the energy powered sensors is still major bottleneck in wide applications of WSNs. From the early days is batteries to renewable energy charging including solar and wind energy, the energy supplies to sensors are unstable. The recent breakthrough of wireless energy transfer techniques brings a new hope that the sensors can be charged by this stable energy supplies. This project aims to developing efficient algorithms for scheduling mobile chargers to sensors with different optimization metrics (represented by sub-modular functions), subject to the energy capacity constraint on mobile chargers.

An excellent background in algorithms and computer networks is compulsory. Also, a good program skill is needed to implement the designed algorithm and evaluate the performance of the proposed algorithms. The produced results are likely to be published in top venues such as top conferences or journals.

*Background literature:*

- W. Liang, Z. Xu, W. Xu, G. Shi, G. Mao, and S. Das. Approximation algorithms for charging reward maximization in rechargeable sensor networks via a mobile charger. To appear in IEEE/ACM Transactions on Networking, acceptance date: June 25, 2017.
- W. Liang, W. Xu, X. Ren, X. Jia, and X. Lin. Maintaining large-scale rechargeable sensor networks perpetually via multiple mobile charging vehicles. ACM Transactions on Sensor Networks, Vol.12, No. 2, Article 14, 2016.
- W. Xu, W. Liang, X. Lin, and G. Mao. Efficient scheduling of multiple mobile chargers for wireless sensor networks. IEEE Transactions on Vehicular Technology, Vol.65, No.9, pp.7670-7683, 2016.

### **2. QoS-Aware Task Offloading in Edge Clouds**

Supervisor: Weifa Liang [[wliang@cs.anu.edu.au](mailto:wliang@cs.anu.edu.au)]

Mobile applications are becoming increasingly computation-intensive, while the computing capacity of mobile devices are limited due to their portable sizes. A powerful approach to improving the performance of mobile applications is to offload some of their tasks to remote clouds, where an application consists of multiple tasks. Existing research in mobile task offloading mostly considered the cloud to be the remote offloading destination, due to its abundance of computational resources. However, the cloud usually is remotely located and far away from its users, and the network delay incurred by transferring data between users and the cloud can be very costly. This is especially undesirable in reality-augmenting applications and mobile multiplayer gaming systems, where a crisp response time is critical to the user's experience. Edge clouds a type of network pushing the access of computation/storage in the edges, servers (or clusters of servers) are co-located at an access point (AP) in a network, and are accessible by users via wireless connection. A key advantage of edge clouds over the cloud, is that the close physical proximity between edge clouds and users enables shorter communication delays, thereby improving the user experience of interactive

applications. This project aims to investigate different strategies to offload tasks while meeting individual user QoS requirement such that the network throughput is maximized.

*Requirements/Prerequisites:*

- An excellent background in algorithms and computer networks is compulsory. Also, good programming skills are needed to implement the designed algorithm and evaluate the performance of the proposed algorithms.

*Background literature:*

- M. Jia, J. Cao, and W. Liang. Optimal cloudlet placement and user to cloudlet allocation in wireless metropolitan area networks. To appear in IEEE Transactions on Cloud Computing, Vol.XX, Acceptance date: May 28, 2015.
- M. Jia, W. Liang, Z. Xu and M. Huang. Cloudlet load balancing in wireless metropolitan area networks. Proc of INFOCOM'16, IEEE, pp.730--738, 2016.
- Q. Xia, W. Liang, and W. Xu. Throughput maximization for online request admissions in mobile cloudlets. Proc of 38th Annual IEEE Conference on Local Computer Networks (LCN), IEEE, Oct, 2013.
- Q. Xia, W. Liang, Z. Xu, and B. Zhou. Online algorithms for location-aware task offloading in two-tiered mobile cloud environments. Proc of 7th IEEE/ACM Intl Conf on Utility and Cloud Computing, Dec., 2014.

### 3. NFV-enabled routing in Software-Defined Networks

Supervisor: Weifa Liang [[wliang@cs.anu.edu.au](mailto:wliang@cs.anu.edu.au)]

Network Function Virtualization (NFV) is emerging as a promising paradigm that is shaping the future networking landscape, by not only bringing the promise of enabling inexpensive and flexible management solutions but also introducing new challenges to the area of network management. Today's data centres and communication networks deploy a variety of intermediary middleboxes, e.g., firewalls, Intrusion Detection Systems (IDSs), proxies, and WAN optimizers, to guarantee the security and performance of data transfers. However, it is very expensive to achieve the benefits of middleboxes in conventional networks, since the middleboxes are typically made by dedicated hardware devices. Underpinned by the NFV technique, Software-Defined Networking (SDN) that separates the control plane from the data plane can be utilized to enable inexpensive and flexible implementation of network functions as software components running in Virtual Machines (VMs), rather than expensive and hard-to-manage hardware middleboxes.

Unicasting and Multicasting in SDNs that transmit data from one source to one or multiple destinations is a fundamental functionality of the networks, which has wide applications. Such requests usually require to forward their traffic to some middleboxes before reaching their destinations for security and performance concerns. To admit the requests with network function requirements, in this project we study NFV-enabled routing in a Software-Defined Network (SDN) with the aims to minimize the implementation cost of each NFV-enabled unicast and/or multicast request or maximize the network throughput for a sequence of NFV-enabled requests, subject to network resource capacity constraints.

*Requirements/Prerequisites:*

- An excellent background in algorithms and computer networks is compulsory. Also, a good program skill is needed to implement the designed algorithm and evaluate the performance

of the proposed algorithms. The outcomes are likely to be published in top conferences and/or journals.

*Background literature:*

- Z. Xu, W. Liang, M. Huang, M. Jia, S. Guo, and A. Galis. Approximation and online algorithms for NFV-enabled multicasting in SDNs. Proc of IEEE ICDCS'17, June, 2017.
- M. Huang, W. Liang, Z. Xu, and S. Guo. Efficient algorithms for throughput maximization in software-defined networks with consolidated middleboxes. To appear in IEEE Transactions on Network and Service Management, Vol.XX, acceptance date: July 6, 2017.
- Z. Xu, W. Liang, A. Galis, and Y. Ma. Throughput maximization and resource optimization in NFV-enabled networks. Proc of IEEE ICC'17, May, 2017.
- M. Huang, W. Liang, Z. Xu, W. Xu, S. Guo and Y. Xu. Dynamic routing for network throughput maximization in Software-Defined Networks. Proc of INFOCOM'16 IEEE, pp.2545--2553, 2016.

#### 4. Generic Reinforcement Learning Agents

Supervisor: Marcus Hutter [[Marcus.Hutter@anu.edu.au](mailto:Marcus.Hutter@anu.edu.au)]

Agent applications are ubiquitous in commerce and industry, and the sophistication, complexity, and importance of these applications is increasing rapidly; they include speech recognition systems, vision systems, search engines, planetary explorers, auto-pilots, spam filters, and robots [RN03]. Existing agent technology can be improved by developing systems that can automatically acquire during deployment much of the knowledge that would otherwise be required to be built in by agent designers. This greatly reduces the effort required for agent construction, and results in agents that are more adaptive and operate successfully in a wide variety of environments [LH07].

*Goals:* Technically, the project is about a recent general approach to learning that bridges the gap between theory and practice in reinforcement learning (RL). General-purpose, intelligent, learning agents cycle through sequences of observations, actions, and rewards that are complex, uncertain, unknown, and non-Markovian [RN03]. On the other hand, RL is well-developed for small finite state Markov decision processes (MDPs) [SB98]. Extracting the right state representations out of bare observations, that is, reducing the general agent setup to the MDP framework, is an art that involves significant effort by designers. The project is to investigate (by simulations or theoretical) recent models [Hut09] that automate the reduction process and thereby significantly expand the scope of many existing RL algorithms and the agents that employ them.

*Requirements/Prerequisites:*

- background in Artificial Intelligence and Machine Learning
- good programming skills
- performing (computer) experiments and analyzing results
- good math skills; linear algebra at the very minimum
- mastering elementary probability calculus

*Students will gain:*

- getting acquainted with state-of-the art RL algorithms
- improving your math skills: linear algebra, statistics, probability, and information theory

*Background literature:*

- [RN10] S.J. Russell and P. Norvig. *Artificial Intelligence: A Modern Approach* Prentice-Hall, Englewood Cliffs, NJ, 3rd edition, 2010.
- [SB98] R.S. Sutton and A.G. Barto. *Reinforcement Learning: An Introduction* MIT Press, Cambridge, MA, 1998.
- [LH07] S. Legg and M. Hutter. [Universal intelligence: A definition of machine intelligence](#). *Minds & Machines*, 17(4):391-444, 2007.
- [Hut09] M. Hutter. [Feature reinforcement learning: Part I: Unstructured MDPs](#). *Journal of Artificial General Intelligence*, 1:3-24, 2009.
- [Hut14] M. Hutter. [Extreme state aggregation beyond MDPs](#). In Proc. 25th Intl. Conf. on Algorithmic Learning Theory (ALT'14), LNAI 8776, pages 185--199.

## 5. Mathematical Foundations of Artificial Intelligence

Supervisor: Marcus Hutter [[Marcus.Hutter@anu.edu.au](mailto:Marcus.Hutter@anu.edu.au)]

The first decade of this century has seen the nascence of the first mathematical theory of general artificial intelligence. This theory of Universal Artificial Intelligence (UAI) has made significant contributions to many theoretical, philosophical, and practical AI questions. In a series of papers culminating in book [Hut05], an exciting sound and complete mathematical model for a super intelligent agent (AIXI) has been developed and rigorously analyzed. The model is actually quite elegant and can be defined in a single line:

$$\text{AIXI} \quad a_k := \arg \max_{a_k} \sum_{o_k r_k} \dots \max_{a_m} \sum_{o_m r_m} [r_k + \dots + r_m] \sum_{q: U(q, a_1..a_m) = o_1 r_1 .. o_m r_m} 2^{-\ell(q)}$$

( $k$ =now,  $a$ =action,  $r$ =reward,  $o$ =observation,  $U$ =Universal TM,  $q$ =program,  $m$ =lifespan,  $l$ =length)

*Goals:* The fundamentals of UAI are already laid out, but there are literally hundreds of fundamental theoretical/mathematical open questions [Hut05, Hut09] in this approach that have not yet been answered. The complexity ranges from suitable-for-short-projects to full PhD theses and beyond.

*Requirements/Prerequisites:*

- excellent math skills, ideally in information theory or probability or statistics
- creativity in finding and constructing proofs
- ability to clearly interpret the meaning of mathematical theorems

*Students will gain:*

- getting acquainted with the most promising mathematical approach to general AI
- working on interdisciplinary research questions
- acquire experience in proving theorems
- advancing your active math skills

*Background literature:*

- [Hut05] M. Hutter. [Universal Artificial Intelligence: Sequential Decisions based on Algorithmic Probability](#). Springer, Berlin, 2005.
- [Hut09] M. Hutter. [Open problems in universal induction & intelligence](#). *Algorithms*, 3(2):879-906, 2009.

## 6. Universal Artificial Intelligence

Supervisor: Marcus Hutter [[Marcus.Hutter@anu.edu.au](mailto:Marcus.Hutter@anu.edu.au)]

The dream of creating artificial devices that reach or outperform human intelligence is an old one. Most AI research is bottom-up, extending existing ideas and algorithms beyond their limited domain of applicability. The information-theoretic top-down approach (UAI) pursued in [Hut05] justifies, formalizes, investigates, and approximates the core of intelligence: the ability to succeed in a wide range of environments [LH07]. All other properties are emergent.

Recently, effective approximations of UAI have been derived and experimentally investigated [VNHUS11]. This practical breakthrough has resulted in some impressive applications. For the first time, without providing any domain knowledge, the same agent is able to self-adapt to a diverse range of interactive environments. For instance, it is able to *learn* from scratch to play TicTacToe, Pacman, Kuhn Poker, and other games by trial and error.

These achievements give new hope that the grand goal of Artificial General Intelligence is not elusive.

*Goals:* The theoretical [Hut05], philosophical [LH07], and experimental [VNHUS11] foundations of UAI are already laid out, but plenty remains to be done to solve the AI problem in practice. The complexity of the open problems ranges from suitable-or-short-projects to full PhD theses and beyond.

*Requirements/Prerequisites:*

- background in AI or ML or statistics or information theory.
- excellent programming or writing or math skills

*Students will gain:*

- getting acquainted with the most comprehensive theory of rational intelligence to date.
- getting experience in writing a literature survey
- advance the state-of-the-art implementation of AIXI and apply it to new (toy/game) problems
- learn how to prove non-trivial theorems.

*Background literature:*

- [Hut05] M. Hutter. [\*Universal Artificial Intelligence: Sequential Decisions based on Algorithmic Probability\*](#), Springer, Berlin, 2005.
- [LH07] S. Legg and M. Hutter. [\*Universal intelligence: A definition of machine intelligence\*](#). *Minds & Machines*, 17(4):391-444, 2007.
- [VNHUS11] J. Veness, K. S. Ng, M. Hutter, W. Uther, and D. Silver. [\*A Monte Carlo AIXI approximation\*](#). *Journal of Artificial Intelligence Research*, 40:95-142, 2011.

## 7. Personalised Learning Recommendations

Supervisor: Qing Wang [[Qing.Wang@anu.edu.au](mailto:Qing.Wang@anu.edu.au)]

Recommendation systems have attracted considerable attention in both research and industry areas. However, there has not been much effort directed at learning recommendations. In this project, a recommendation engine for supporting personalised learning will be built based on learning behaviour analysis. Domain knowledge will be incorporated into such a recommendation engine in order to improve recommendations using content-based and collaborative filtering techniques.

*Requirements/Prerequisites:*

- Strong skills in programming (C++, Java or Python) are required. Solid knowledge background in data mining and machine learning are desired.

*Students will gain:*

- A solid understanding of content-based and collaborative filtering recommendation techniques, and learn how to implement and apply these techniques into a real-world application setting.

## 8. Building an Integrated Learning Platform based on Knowledge Graphs

Supervisor: Qing Wang [[Qing.Wang@anu.edu.au](mailto:Qing.Wang@anu.edu.au)]

Knowledge graphs have gained increasing popularity in recent years. It has been used in a wide range of areas, including Google's search engine, personalised recommendations, image classification, etc. This project aims to analyse and model knowledge graphs in the area of data analytics, and then based on that, to develop an adaptive learning platform that can integrate various learning resources and tools for supporting learners in an interactive learning environment.

*Requirements/Prerequisites:*

- Strong skills in web application development are required. Solid knowledge background in data mining and relational database are desired.

*Students will gain:*

- A solid understanding of key techniques used in the area of data analytics, and learn how to integrate these techniques together to support data analytics tasks.

## 9. Discovering Inconsistent Data in a Dynamic World

Supervisor: Qing Wang [[Qing.Wang@anu.edu.au](mailto:Qing.Wang@anu.edu.au)]

Inconsistent data exists everywhere but not always evident. However, using inconsistent data may lead to poor decision making, expensive mistakes, communication chaos, etc. There is an increasing industry-driven demand for tools that can efficiently identify and reduce inconsistent data. One

important aspect in developing such tools is to find efficient and effective ways of capturing the structure and semantics of data which will enable the detection of inconsistent data.

The project aims to analyse and mine patterns of inconsistencies occurring among data, and then develop efficient algorithms to capture and resolve inconsistent data based on such patterns.

*Requirements/Prerequisites:*

- Strong skills in software development (Java or Python) are required. Solid knowledge background in data mining and relational database are desired.

*Students will gain:*

- A solid understanding of data mining and database technologies, and learn how to use these techniques to analyse data and improve data quality.

## 10. Detecting emotion recognition by humans

Supervisor: Tom Gedeon [[tom@cs.anu.edu.au](mailto:tom@cs.anu.edu.au)]

Our group has shown that machine learning algorithms using physiological sensors can outperform the person who is the source of the physiological data in some emotion recognition tasks. A plausible reason is that we do not consciously have access to much of the emotion processing parts of our brains. This project will create some data sets for emotions we have not yet investigated and use physiological sensors attached to experimental subjects to record their reactions. Data will be analysed using neural/deep learning techniques. There is scope for two students working together in this area.

*Requirements/Prerequisites:*

- An interest in human experiments, particularly relating to human internal states such as emotion
- An interest in bio-inspired computing techniques, particularly neural
- A willingness to have fun learning how computers can be made to be more useful and responsive to human beings.

*Students will gain:*

- Practical experience in design and conduct of human experiments
- Experience in advanced data analysis and prediction.

## 11. Sensors and stimuli in human classification and learning

Supervisor: Tom Gedeon [[tom@cs.anu.edu.au](mailto:tom@cs.anu.edu.au)]

Our group has shown that machine learning algorithms using physiological sensors can sometimes outperform the person who is the source of the physiological data. A plausible reason is that we only consciously have access to a simplified set of rules rather than the full non-symbolic decision making

machinery of our brains. This project will use various sensor and stimuli devices in human decision making tasks to further investigate this area. There is scope for two students working together in this area.

*Requirements/Prerequisites:*

- An interest in human experiments particularly relating to human internal states such as emotion, stress, anxiety and so on
- An interest in bio-inspired computing techniques
- A willingness to have fun learning how computers can be made to be more useful and responsive to human beings.

*Students will gain:*

- Practical experience in design and conduct of human experiments
- Experience in advanced data analysis and prediction.

## **12. Human Centred Computing / Bioinspired Computing projects**

Supervisor: Tom Gedeon [[tom@cs.anu.edu.au](mailto:tom@cs.anu.edu.au)]

Please see my own student projects page at <http://cs.anu.edu.au/people/Tom.Gedeon/projects.html> for the current list of my projects. They range from human centred projects using eye gaze, physiological signals, EEG, fNIRS and other sensors, and effectuators such as electrical body and brain stimulation; bioinspired projects using neural networks, deep learning or evolutionary algorithms; or a combination of both human centred and bio-inspired. There is scope for multiple students in these areas.

*Requirements/Prerequisites:*

- An interest in human experiments particularly relating to human internal states such as emotion, stress, anxiety and so on
- An interest in bio-inspired computing techniques
- A willingness to have fun learning how computers can be made to be more useful and responsive to human beings.

*Students will gain:*

- Practical experience in design and conduct of human experiments
- Experience in advanced data analysis and prediction.

### 13. Automated Reasoning for Artificial Intelligence

Supervisor: Raj Gore [[rajeev.gore@anu.edu.au](mailto:rajeev.gore@anu.edu.au)]

Much current research in Artificial Intelligence currently utilises non-classical logics called modal logics. These logics can capture notions like time, space, obligation, knowledge, belief etc. which classical logic cannot do as easily. But the interests of AI researchers rarely looks at the task of actually building efficient reasoners for such logics. We have recently developed automated theorem provers for very expressive modal logics. Are they any good for AI research?

The goal of the project is to build more specialised automated reasoners for logics with applications in Artificial Intelligence. We have a framework, we need help to tailor it to the needs of AI.

*Requirements/Prerequisites:*

- A strong background in maths or logic would be extremely useful but is not necessary. Of more importance is enthusiasm and an interest in the formal side of AI. You will need to learn the theory of modal logics and how to automate them. Then you will need to learn the uses of these logics in AI. Finally, you will need to use our technology to build the provers that are needed by AI researchers.

*Students will gain:*

- This project will introduce you to an area of theoretical computer science which mixes theory and practice and may lead to a publication. It will form a good basis for doing a PhD, either with us or at another university.

### 14. A Framework for Implementing Modal Logics Using the BDD Method

Supervisor: Raj Gore [[rajeev.gore@anu.edu.au](mailto:rajeev.gore@anu.edu.au)]

Modal logics extend classical propositional logic by adding a unary connective  $\Box$  with  $\Box A$  interpreted as any of the following: "A is known", "A is believed", "A is necessary". The models for modal logics are graphs where  $W$  is a set of points/vertices/states and  $R$  is a set of edges connecting these points/vertices/states. By stipulating further restrictions on these edges, we can obtain many different propositional modal logics which greatly extend the expressive power of classical propositional logic. For example:  $R$  is reflexive: for all  $x$ .  $R(x,x)$   $R$  is serial: for all  $x$  exists  $y$  such that  $R(x,y)$   $R$  is transitive: for all  $x,y,z$ .  $R(x,y)$  and  $R(y,z)$  implies  $R(x,z)$   $R$  is euclidean: for all  $x,y,z$ .  $R(x,y)$  and  $R(x,z)$  implies  $R(y,z)$   $R$  is symmetric: for all  $x,y$ .  $R(x,y)$  implies  $R(y,x)$ . In almost all of these logics, the models for a formula  $A$  can be built from the subsets of the set  $\text{subfml}(A)$  of all subformulae of  $A$ , ignoring all other formulae which are not relevant to  $A$ . A simple way to test if a given formula  $A$  has any models is then to just enumerate these subsets and check if any of them can support a model for  $A$ . This naive method has an average and best case complexity which is exponential in the size of  $A$  since a formula of length  $n$  has at most  $n$  subformulae and the size of  $\text{subfml}(A)$  is then  $2^n$ . Recently, it has been shown that this method can be made practical by using binary decision diagrams (BDDs) as the underlying data structure. ,>

The project is to build a framework which accepts an arbitrary collection of restrictions on R and which outputs a theorem prover specially designed for the modal logic captured by those restrictions.

*Requirements/Prerequisites:*

- It will involve significant amounts of programming using BDDs and will suit someone who enjoys both theory and practice.

*Students will gain:*

- Successful completion is likely to lead to a publication.

*Background literature:*

- BDD-Based Automated Reasoning for Propositional Bi-Intuitionistic Tense Logics. Rajeev Gore, Jimmy Thomson Proc. IJCAR 2012: International Joint Conference on Automated Reasoning 2012. Lecture Notes in Computer Science, volume 7364, pp 301-315, Springer 2012.

## 15. Semantic Web: modularisation and pruning of large ontologies

Supervisors: Kerry Taylor [[Kerry.Taylor@anu.edu.au](mailto:Kerry.Taylor@anu.edu.au)], Dirk Pattinson [[Dirk.Pattinson@anu.edu.au](mailto:Dirk.Pattinson@anu.edu.au)].

Ontologies represented using the W3C-standard Web Ontology Language (OWL) model knowledge as logical axioms. Currently many Australian Government and private enterprises are developing large OWL ontologies to enable interoperability for data sharing, supported by underlying formal reasoning. Large ontologies can be very difficult in practice for both human understanding and for many software tools, yet many applications of ontology really only need to focus on only a small part of a larger picture.

For this project, we would look evaluate a range of ontology modularisation (design-stage) and pruning (application-stage) approaches from both the academic literature and industrial practice, in order to develop benchmark evaluation criteria and to critique methods against that criteria. This will require conversations with practitioners and also implementation and testing of methods in software.

There may be an opportunity to co-author an academic publication and to pursue the topic in an honours or PhD research project.

*Background literature:*

- Tim Berners-Lee, The next web, TED talk 2009.  
[https://www.ted.com/talks/tim\\_berniers\\_lee\\_on\\_the\\_next\\_web](https://www.ted.com/talks/tim_berniers_lee_on_the_next_web)
- Alan L Rector, Modularisation of Domain Ontologies Implemented in Description Logics and related formalisms including OWL, Proc K-CAP 2003.  
<http://www.cs.man.ac.uk/~rector/papers/rector-modularisation-kcap-2003-distrib.pdf>

- Zubeida Casmod Khan and C. Maria Keet, An empirically-based framework for ontology Modularization, Applied Ontology 10, 2015.  
<http://pubs.cs.uct.ac.za/archive/00001048/01/AO15modulesPaper.pdf>