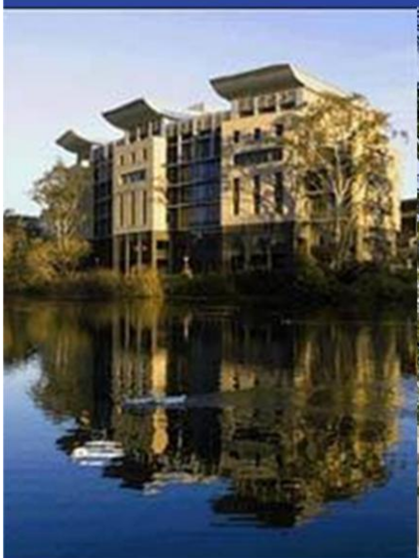
Thinking Systems: Navigating Through Real and Conceptual Spaces



22 November 2010

Information Technology & Electrical Engineering,
Queensland Brain Institute, University of Queensland;
Queensland University of Technology
Supported by the Australian Research Council's Special Research Initiative on Thinking Systems

Thinking Systems:
Navigating Through Real and Conceptual Spaces

Project Summary

This project brings together a cross-disciplinary, collaborative and cross-institutional team to study fundamental issues in how information is transmitted, received, processed and understood in biological and artificial systems. The core of the project is studying how brains understand spatial systems, both physical and conceptual. This integrated approach is leading to an increased understanding of neural, behavioural and information processing bases of thinking systems. Insights from neurocognitive systems are being used to develop computational models, autonomous robots and intelligent software agents, which in turn are leading to deeper understandings of the relationships between neurocognitive mechanisms and their behaviour in whole systems.

Project Team

Professor Janet Wiles
Professors Perry F. Bartlett
Professor Kevin Burrage
Professor Geoffrey J. Goodhill
Professor Jason B. Mattingley
Professor Pankaj Sah
Dr. Andrew E. Smith
Professor M.V. Srinivasan
Professor Gordon F. Wyeth
Professor Michael A. Arbib
Professor Jeffrey L. Elman
Professor John M. O'Keefe

Thinking Systems Symposium
Program

Monday 22 November 2010

10.30 – 11.00am	Tea/Coffee
11.00 – 11.10am 11.10 – 11.30am	Janet Wiles: *Welcome* Richard Coleman: *Opening Address*
11.30 – 12.00pm	Mandyam Srinivasan and Tien Luu *“Insect Navigation”*
12.00 – 12.30pm	Pankaj Sah and Francois Windels *“Using Place Cells in Goal-Directed Behaviour: Rodent Electrophysiology”*
12.30 – 1.00pm	Gordon Wyeth and Michael Milford *“Brain-Based Robot Navigation”*
1.00 – 1.30pm	Lunch
1.30 – 2.00pm	Jason Mattingley and Oliver Baumann *“Neural and Behavioral Correlates of Human Navigation”*
2.00 – 2.30pm	Andrew Smith and Daniel Angus *“Concept Mapping Inspired by Physical Navigation”*
2.30 – 3.00pm	Allen Cheung *“Mathematical and Computational Theory of Animal Navigation”*
3:00 – 3:15pm	Tea/Coffee
3.15 – 3.45pm	Peter Stratton *“Understanding the Dynamics and Function of Networks of Spiking Neurons”*
3.45 – 4.15pm	David Ball *“Engineering, Technology and Robotics”*
4.15 – 5.15pm	Jeff Elman: *Closing Address*
5.15 – 5.30pm	Discussion
5.30pm	Close

Director's Report

The deep mysteries of how the brain navigates in physical and conceptual space are studied by a diverse range of disciplines and have potential applications from health to the development of new technologies. Navigation is a fundamental ability for movement through both physical and conceptual worlds. Taken for granted until something goes wrong, physical navigation is essential not just for animals (from insects to mammals), but also for autonomous robots. Just as places are organised using physical maps, so concepts are organised using concept maps. Conceptual navigation enables humans to make sense of the complex world of ideas – possibly using neural circuits evolved for physical navigation.

The aim of the Thinking Systems Navigation project is to integrate disciplinary approaches from neuroscience, robotics and information science. The strength of the project lies in its personnel, and the research themes have been led by an outstanding group of researchers across a range of disciplines, joined by an extremely talented group of research fellows and students who have been learning the many interdisciplinary skills involved. Our neuroscientists have drawn on engineering and computational modelling for new tools and techniques, and our roboticists and information systems scientists have been inspired by biological navigation to develop novel technologies. Highlights reported in the following pages include insights into honeybee flight using a bee-sized virtual reality world, algorithms for robots inspired by rodent navigation, the identification of specialised brain regions for heading direction in human navigation, and a new rat-sized robot (the iRat) controlled by spiking neural models. Interdisciplinary research also leads to unexpected and beneficial applications, and we report for the first time on visualization of text as a path through a conceptual space, which is leading to understanding of communication in a diverse range of conditions including autism, schizophrenia and dementia.

We are proud of the depth as well as the breadth of our interdisciplinary work in neuroscience, computational science, robotics and information visualization. The quality is recognised by acceptance in highly acclaimed international journals and refereed conferences, with publications in 2009 including *International Journal of Human-Computer Studies, Journal of Neurophysiology, PLoS One, International Symposium of Robotics Research,* and *IEEE International Conference on Information Visualization*; and in 2010 in *International Journal of Robotics Research, Journal of Neurophysiology, Journal of Neuroscience* (2), *Journal of Theoretical Biology* (2), *NeuroImage* (2), *PLoS Computational Biology* (2), *Robotics and Autonomous Systems, International Conference on Robotics and Automation* (2*), International Conference on Artificial Life*, and *International Conference on Neural Information Processing* (2). Our trajectory has continued to develop, with 13 refereed publications in 2009 (46% in ERA A) and 22 in 2010 (73% in ERA A* and A). Impressively, 50% of our journal publications in 2010 were ERA A* ranked (i.e. in the top 5% of journals). Our research is also producing commercial benefits with three patents to date, one in 2009 for information visualisation, which has been licensed to the text analytic company Leximancer Pty Ltd, and two in 2010 in robotics and information visualisation, with commercialisation under discussion.

Collaboration has been a guiding principle of the project since its inception. Funded by the ARC Special Research Initiative in Thinking Systems since mid 2006, the early years of the project involved establishment of our collaborative structure – weekly meetings of all members of the project, with a focus on presentations led by the Chief Investigators in the first year, the postdocs and research students in the second and third years, and collaborative endeavours between two or more postdocs in the last year. National and international visitors have contributed throughout the project, and we have benefitted especially from extended visits by our international Partner Investigators. In 2009 we hosted a joint Symposium of the three Thinking Systems projects, a highly successful Summer School on Animal Navigation, and over summer 2009-2010 organised a lecture series with internationally renowned speakers and an associated special topics course "Summer of Spikes" on spiking neurons, networks and oscillations in the brain. Computational modelling has been central to the project for understanding the theoretical principles and computational algorithms for physical and conceptual navigation. An unusual strength of the collaboration across disciplines has been the joint supervision of research and research experience students, with engineering students contributing particularly to the development of new technologies and models in neuroscience and benefitting from placements in neuroscience labs. Cross-disciplinary fertilisation has enabled rapid development of new technologies for investigation of navigation in bees, rodents, humans, and biological inspiration of head-direction, place and grid cells for robotics.

The TS Navigation project is entering its final year of funding, and we anticipate that the innovations of the past four years will continue, with an ongoing and upward trajectory of excellent results into 2011 and beyond. The speed with which new approaches and technologies have been developed has been due to two major factors – the critical mass of outstanding researchers and the range of disciplines that have focussed on the challenges. Our diverse and high quality achievements show the benefits of funding exciting interdisciplinary projects spanning science and technology.

Professor Janet Wiles
Director, Thinking Systems Navigation project
School of Information Technology and Electrical Engineering,
and adjunct Professor in the Queensland Brain Institute.
November 2010.

Opening Address

Professor Richard Coleman

Executive Director for Physical, Mathematical and Information Sciences, Australian Research Council

Professor Coleman joined the ARC in July 2009 as Executive Director for Physical, Mathematical and Information Sciences. Prior to this, he was the Professor of Marine Science and Director of the Centre for Marine Science at the University of Tasmania (UTAS), and also the Director of the joint CSIRO-UTAS PhD Program in Quantitative Marine Science.

Professor Coleman was a member of the ARC College of Experts on the Physics, Chemistry and Earth Sciences panel since 2008.

He has over 25 years experience as a researcher and academic in the Australian university sector. Professor Coleman has held positions at the Research School of Earth Sciences, the Australian National University, the University of Sydney, and the University of Tasmania—where he also held a joint appointment with CSIRO Marine and Atmospheric Research.

Professor Coleman has taught a wide range of undergraduate and graduate courses in the physical sciences (spatial information, earth, and marine sciences). He has a wealth of experience in graduate supervision, with some 27 completions, and has served as Acting Dean of Graduate Research at the University of Tasmania.

Professor Coleman holds a Bachelor of Surveying (Hons 1) and a PhD in Geodesy from the University of New South Wales. He has received a Fulbright postgraduate award and Queen's Fellowship in Marine Science and has been a visiting scientist at universities and research institutions in France, Japan and the United States.

Throughout his career, Professor Coleman has been awarded more than $13 million in research funding from nationally competitive research grants over 20 years. His research comprised geodesy, physical oceanography and glaciology, with the main focus based on understanding the role of the oceans and cryosphere in the global climate system by using observations, theory and modelling.

Professor Coleman has written more than 90 publications in peer-reviewed journals.

Closing Address

Professor Jeffrey L. Elman

Jeffrey L. Elman has made several major contributions to the theoretical foundations of human cognition, most notably in the areas of language and development. His work has had an immense impact across fields as diverse as cognitive science, psycholinguistics, developmental psychology, evolutionary theory, computer science and linguistics. Elman's 1990 paper Finding Structure in Time introduced a new way of thinking about language knowledge, language processing, and language learning based on distributed representations in connectionist networks. The paper is listed as one of the 10 most-cited papers in the field of psychology between 1990 and 1994, and the most often cited paper in psycholinguistics in that period. This work, together with earlier Elman's earlier work on speech perception and subsequent work on learnability, representation, innateness, and development, continues to shape the research agendas of researchers in cognitive science, psycholinguistics, and many other fields.

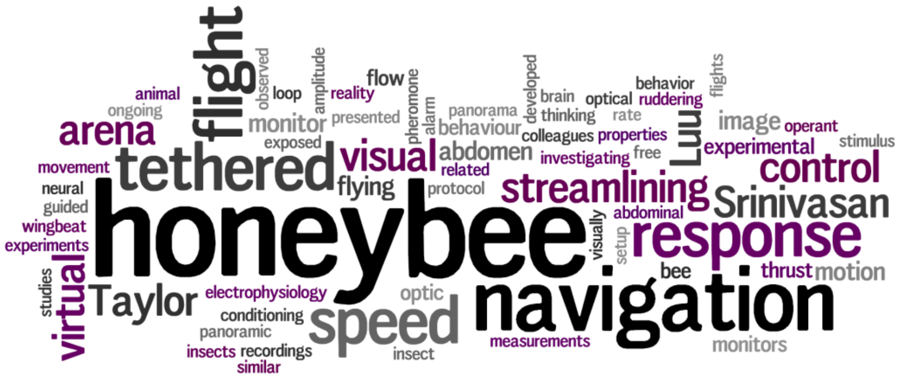
Elman received his Bachelor's degree from Harvard in 1969 and his Ph.D. in Linguistics from the University of Texas in 1977. That same year he joined the faculty at UCSD, where he has remained ever since, first in the department of Linguistics and now in the Department of Cognitive Science. He is now Distinguished Professor in the Department of Cognitive Science, as well as Dean of the Division of Social Sciences and Co-Director of the Kavli Institute for Brain and Mind.

In the early 1980's, Elman was among the first to apply the principles of graded constraint satisfaction, interactive processing, distributed representation, and connection-based learning that arose in the connectionist framework to fundamental problems in language processing and learning. His early work concentrated on speech perception and word recognition, leading to the co-development (with Jay McClelland) of TRACE, an interactive-activation model that addressed a wide range of findings on the role of context in the perception of speech. Elman's subsequent work on language learning in Simple Recurrent Networks has been revolutionary.

Many of Elman's ideas about ontogeny were worked out in detail with several colleagues in the 1996 book, Rethinking innateness: A connectionist perspective on development, where the Nature-Nurture controversy is redefined in new terms.

Elman has also been a leading contributor as a scientific citizen, working continually to build bridges between the disciplines that contribute to the field of Cognitive Science. For many years, Elman directed the UCSD Center for Research in Language, where he turned a local resource into an internationally renowned research unit. At the international level, Elman has been an active member of the Governing Board for the Cognitive Science Society. He has served as President of the society, and serves as consultant and advisory board member of many departments and institutions, and on the editorial board of numerous journals.

Elman was the recipient of The David E. Rumelhart Prize (2007), for Contributions to the Theoretical Foundations of Human Cognition. In short, Elman exemplifies the kind of model that David Rumelhart set for our field, not only in the quality and depth of his science, but in the degree of compassion, leadership and generosity that he provides to his colleagues around the world.



Theme 1: Neural Mechanisms for Navigation

This theme is investigating neural mechanisms for navigation in insects via electrophysiology and behavioural observation. This research is helping design computationally efficient and reliable algorithms for autonomous navigation.

Project Members

Theme Leader	Mandyam Srinivasan
Chief Investigators	Pankaj Sah, Perry Bartlett, Gordon Wyeth, Geoffrey Goodhill, Janet Wiles
Research Fellow	Tien Luu
PhD Student	Gavin Taylor
Research Assistants	Gavin Taylor (2009), Justin Cappadonna (2009)
Collaborators	In Thinking Systems: Allen Cheung, David Ball In QBI: Judith Reinhard
Research Experience Students	Timothy Mews (2008-09), Gavin Taylor (2008-09)

Insect Navigation

Tien Luu

Summary

Honeybees are excellent foragers, able to find food sources at sites up to 10km away from their hive. Their ability to find these sites and subsequently communicate the location of the food source to other worker bees upon their return clearly demonstrates their exceptional navigational abilities. Thus the honeybee provides an ideal experimental model to better understand the neural substrates of insect navigation.

Honeybee and Virtual Reality

A large body of published experimental data exists on freely flying honeybees in tunnel and maze experiments, much of which were conducted by theme leader M. Srinivasan and colleagues. Under Professor Srinivasan's leadership, we have recently developed an experimental paradigm to investigate visually guided insect flight and navigation using tethered honeybees in a virtual reality arena. The virtual arena was constructed with the help of my Thinking System colleagues, Allen Cheung and David Ball. With their help, geometrically accurate 3D arenas could be rendered in real time on up to 4 monitors simultaneously, creating a panoramic visual environment which simulates motion. This 3D environment has been successful in initiating and maintaining flight behaviour in tethered honeybees.

The successful use of virtual reality in studying insect navigation has also paved the way for Gavin Taylor, a PhD student, who has adapted the current experimental paradigm to include force sensor measurements. It is envisaged that these measurements may be used to control movement within the virtual world, thus allowing the tethered honeybee to perform virtual free flights. This experimental setup allows for precise control of the visual environment, tracking of flight trajectories and being tethered, it will be possible to carry out electrical recordings from neurons in the honeybee brain during navigation and other tasks.

Honeybee flight: A novel 'streamlining' response (manuscript under revision)

The simulation of moving scenes shown across two standard LCD computer monitors, constituting less than half the visual panorama, has been shown to be sufficient to induce flight-like behaviour in tethered honeybees. The initiation and maintenance of flight-like behaviour purely by image motion (optic flow) has not been shown in insects. Using this virtual reality experimental setup an interesting, novel behavioural response was observed. The abdomen showed a 'streamlining' response when the bee was exposed to image motion that simulated forward flight (Fig. 1). Interestingly, this response is visually driven, and not due to aerodynamic drag, since there is no change in air resistance whilst tethered. We also observed this 'streamlining' response in 7 day old bees, which are known to be too young to have flight experience let alone performed outdoor foraging. This suggests the 'streamlining' behaviour may be an innate response of the honeybee and possibly of insects.

Figure 1. Changes in the abdominal position of the honeybee were observed when it was exposed to simulated forward image motion. The video footage of the flight behaviour were analysed using Matlab. The positional changes of the abdomen were tracked by measuring the long axis of the abdomen relative to the horizontal axis through the head and thorax.

Panoramic motion vision in honeybees

In further experiments, we have implemented a panoramic virtual arena consisting of four LCD monitors. The 'streamlining' flight response was observed in both the 2- and 4-monitor setups. However, bees were observed to maintain the 'streamlining' posture for much longer periods when tested in the four monitor setup. Strikingly, this streamlining response remained the same irrespective of whether the virtual world was displayed with the two front, two rear or two diagonal monitors only. When two active monitors were presented to the bee, as the speed of image motion was progressively increased, the abdomen was raised progressively higher, up to a certain speed, beyond which the abdomen dropped with further increase of image speed. In contrast, using the same image speed protocol in the 4-monitor setup, the abdomen was raised progressively higher and would then remain elevated for the entire image speed stimulus (Fig. 2). Other flight properties have also been investigated using this 4-monitor setup. Some of the properties that we have examined include the honeybee's abdominal flight response to contrast and to spatial frequency.

In addition, we have also completed studies examining the changes in wingbeat amplitude during the honeybee's streamlining response. Combining these data with flight thrust measurements, a second manuscript is in preparation tentatively titled "Relationship between flight thrust, wingbeat amplitude and streamlining response in tethered, flying honeybees."

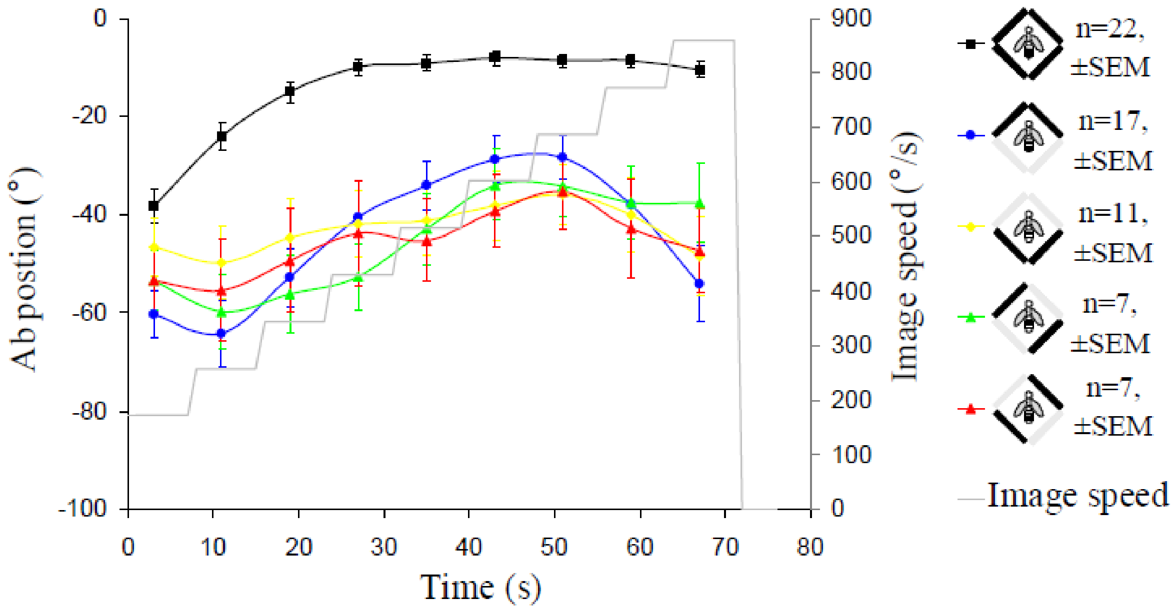


Figure 2. The abdominal positions of tethered bee flights were tracked during testing in the various 2 and 4 monitor configurations. All flights were presented with the ascending image motion speed protocol. Note that the abdominal positional changes were similar regardless of the different 2 monitor configurations, but were in stark contrast to those flights tested in the 4 monitor set up, in which the abdomen remained in an elevated position for most the image speed protocol.

Honeybee electrophysiology

Colleagues from the Drosophila lab (B. van Swinderen, A. Paulk) at QBI routinely obtain multi-unit recordings from the honeybee and Drosophila brain. With their help a rig for honeybee electrophysiology has been set up and preliminary extracellular spike recordings from the honeybee brain have been successfully obtained. By performing extracellular recordings in live honeybees in the virtual reality arena, a number of interesting projects are being pursued. One of the projects is to identify the candidate cellular substrates of navigation, for example, the honeybee odometer. Another ongoing project is to examine the responses of motion sensitive neurons to the alarm pheromone. In the wild, when freely flying honeybees catch a whiff of the alarm pheromone, their flight behaviour changes dramatically, from normal meandering flying to increased speed and straight flight attack trajectory to the nearest perceived predator/intruder.

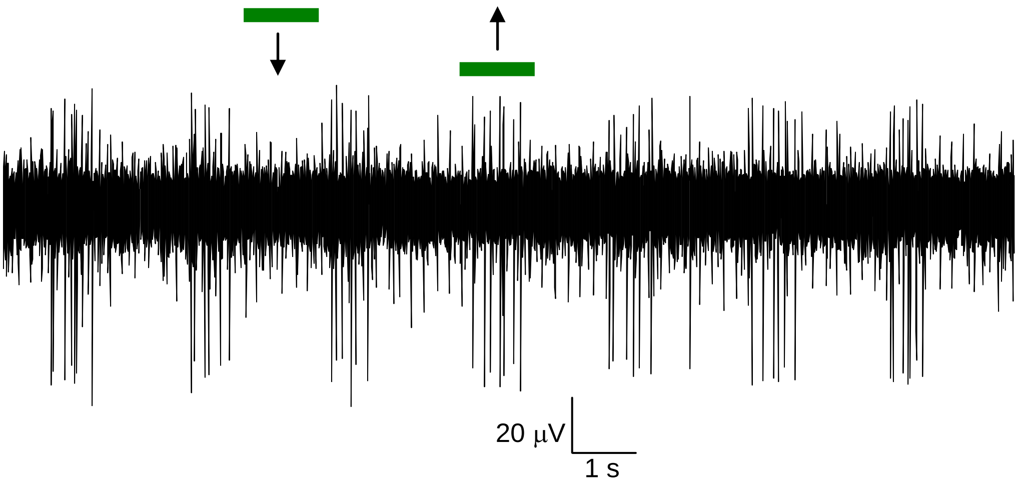


Figure 3. Recordings from motion-sensitive neurons in live honeybees have recently been made. The figure below shows neuronal action potentials firing in response to a green horizontal bar that was moving upwards. There was no firing when the bar moved in the opposite direction, i.e. downwards. The bar was moving at a frequency of 1Hz.

Ongoing Collaborative Research

Properties of tethered honeybee flights in virtual reality – in collaboration with Thinking Systems colleagues, Allen Cheung and David Ball.

The effect of alarm pheromone on motion sensitive neuron in the honeybee - in collaboration with Dr Judith Reinhard.

Submissions

Luu, T., Cheung, A., Ball, D., Srinivasan, M. “Honeybee flight: A novel ‘streamlining’ response,” Journal of Experimental Biology (under revision).

Conference Abstracts or Poster

Luu, T., Cheung, A., Ball, D., Srinivasan, M.V. (2010) “Honeybee flight: A novel ‘streamlining’ response” Poster: 9th International Congress on Neuroethology. Salamanca, Spain.

Luu, T. (2009) Presented at the International Union for the Study of Social Insects conference (IUSSI), Brisbane, QLD.

Related Activities

Attended the Summer School of Animal Navigation held at the Australian National University, ACT, 2008.

Helped with the organization of the Summer School on Animal Navigation (UQ, 2009).

Demonstrator for the Bee Brain Challenge from 2008- 2010.

Media Coverage

Helped the SBS /BBC film crew (Stefan Moore, producer) shoot tethered honeybee flights. The movie clip was used in the “Honeybee Blues” documentary shown in Qantas iQ Inflight documentaries. Credited as “Bee wrangler”.

Supervision of student related to Thinking Systems

Supervising Gavin Taylor, a PhD student. Project title: Investigating visually guided flight behaviour of honeybees in a virtual-reality flight arena.

Investigating Visually Guided Flight Behavior of Honeybees in Virtual-Reality Flight Arena

Gavin Taylor

Flying honeybees use visual information for tasks ranging from low-level speed control and obstacle avoidance to higher-level navigation tasks. Honeybee's visual behavior can potentially be used to inspire novel visually guided robotic control systems. However, visually guided honeybee behavior has previously only been studied in free flight conditions. In laboratory studies, honeybees are typically placed in very restrained harnesses and have difficulty learning visual cues.

I have developed a novel assay where tethered honeybees fly in a virtual-reality flight arena. A panoramic visual stimulus is displayed to the tethered honeybee, and a force transducer measures the honeybees thrust. This feedback is used to close the loop between the bee's decision and the movement speed of the visual panorama it experiences.

Figure 1: (a) Tethered honeybee, (b) View of tethered bee in virtual-reality arena.

Preliminary experiments show honeybees attempt to maintain a constant rate of optic flow in the arena, as expected from free flight studies. In the presence of a headwind, they raise their thrust output to restore the optic flow rate they experience. Honeybees are able to learn to use alternate motor outputs to control the speed of the visual panorama they see, showing low-level operant conditioning.

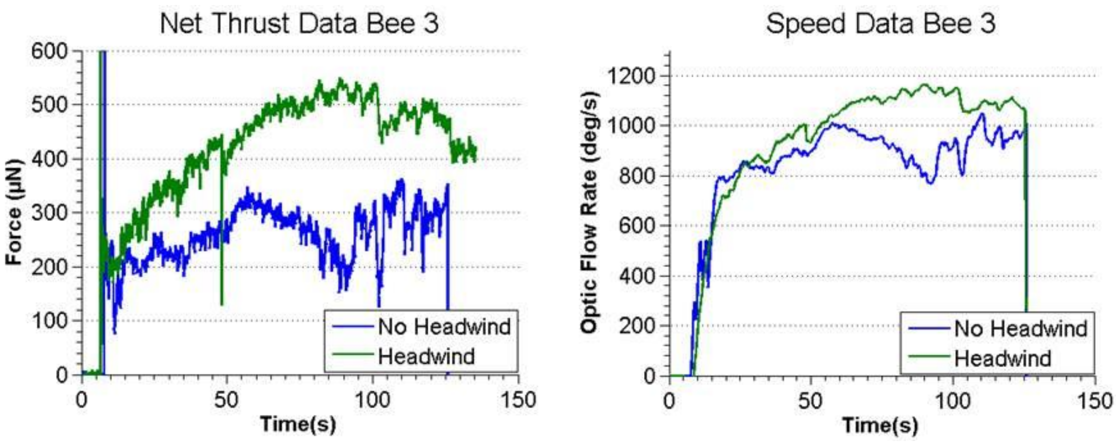


Figure 2: (a) Honeybees raise their thrust in the presence of headwind, which maintains a similar rate of optic flow as in the no wind condition (b).

When flying along a tunnel in free flight, honeybees fly centrally such that each eye experiences an equal rate of optic flow. When exposed to unbalanced optic flow cues in the arena, honeybees make ‘ruddering’ movement using their abdomens. This ruddering behavior may indicate the honeybees are trying to control their yaw when flying in the arena.

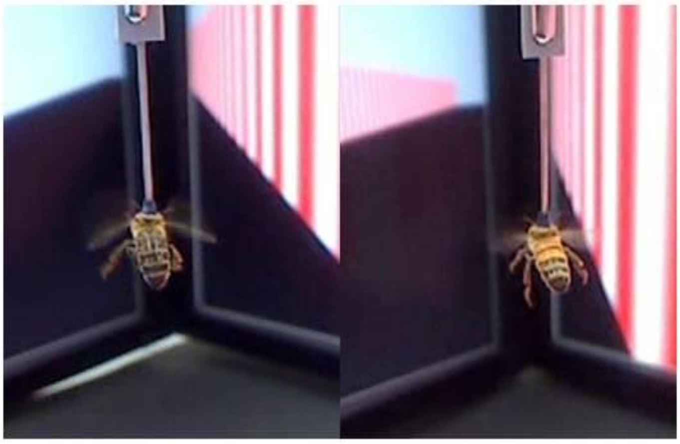


Figure 3: Honeybees display a ruddering behavior when shown unbalanced optic flow.

With the virtual-reality flight arena now nearly finished being developed, my future work will concentrate on behavioral studies using this assay:

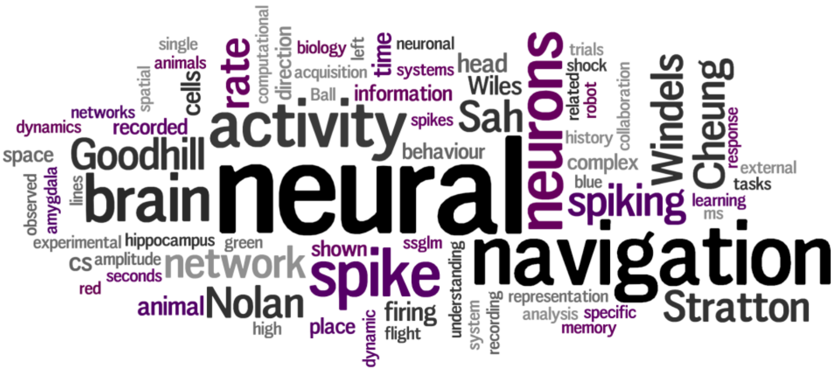
- Analysis of the honeybees speed control system will be undertaken. This will look at the robustness, response to disturbances, and the effect of the scene’s visual properties.
- Operant conditioning of the honeybee to use alternate motor outputs to control its flight speed will be conducted. This efficacy will be compared to when it uses thrust.
- The correlation between the thrust produced by the honeybee and optical measurements of its wingbeat amplitude will be measured. I will evaluate the possibility of using optical measures of the wingbeat for closed loop control.
- Yaw control for the tethered bee using an optical measure of its ruddering will be implemented. This will allow investigation of the centring response and obstacle avoidance.
- Operant conditioning of the honeybee to visual cues that is similar to navigation in free flight will be developed. I will investigate how the honeybee uses landmarks and visual odometry to remember goals.

Ongoing Collaborative Research

This work is done in collaboration with my supervisors Tien Luu, David Ball and Mandyam Srinivasan. Tien Luu pioneered the method of open loop tethered flight in a virtual-reality arena that I have expanded on. David Ball wrote a program to display panoramic visual stimulus on four computer monitors that I have used.

Related Activities

I attended the 8th ACEVS-CVS Summer School on Animal Navigation.



Theme 2: Spatial maps and neurally inspired algorithms

This theme is investigating neural mechanisms for navigation freely behaving rodents via electrophysiology and behavioural observation. It also investigates fundamental computational principles involved in generating, updating and using efficient spatial representations, and developing mathematical and computational models inspired by neurophysiological and neurocognitive data from insects, rodents and humans.

Project Members

Theme Leader	Pankaj Sah
Chief Investigators	Geoffrey Goodhill, Kevin Burrage, Janet Wiles, Perry Bartlett, Jason Mattingley, Gordon Wyeth
Research Fellows	Francois Windels, Allen Cheung, Peter Stratton
Technology Support	Tim Martin (2010) Robert Ninness (2008-2009)
Collaborators	In Thinking Systems: Daniel Angus, David Ball, Michael Milford, Chris Nolan
Research Experience Students	Kieran McLean (2009-10), Nabeelah Ali (2008-09), Robert Ninness (2008-09), Benjamin Sinclair (2008-09)

Using Place Cells in Goal-Directed Behaviour: Rodent Electrophysiology

Francois Windels

Theme 2A project focuses on how contextual information from the hippocampus is used in learnt and newly acquired behaviour. The underlying hypothesis is that the hippocampus provides both contextual and positional information to other brain regions like the amygdala, where it can be associated with other relevant information to form new memories. We use deep brain moveable multi-wire electrodes to record neuronal assembly activity over days or weeks (figure 1). Electrical activity is screened over several days and electrode placement adjusted accordingly to ensure that the largest number of neurons can be recorded with a high signal to noise ratio.

The neuronal mechanisms underlying associative learning in the amygdala were first studied using non-spatial tasks to establish a reference framework that can be compared with published results. An auditory stimuli (CS+) was repeatedly paired with an aversive shock (US), while a non paired auditory tone (CS-) was also played to provide a baseline response to auditory stimuli throughout the experiment (figure 2A). Single neuron responses to the acquisition of this new association are shown on Figure 2B and 2C.

The dynamic response of individual cells to each pairing was also studied using a statistical model (state-space general linear model, SS-GLM, Czanner et al. 2004), which accounts for the pre-stimuli spiking history and pairing to pairing changes (Figure 3).

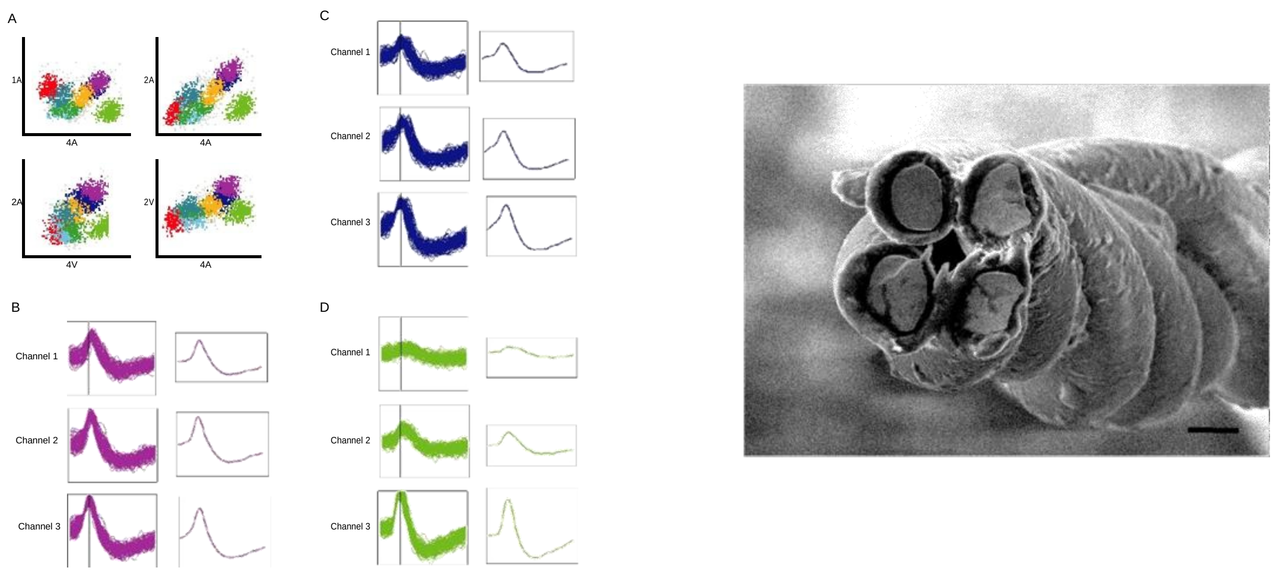


Figure 1. Individual neurons in the basolateral amygdala were identified from tetrode recordings (left). A. Spike clustering of a single tetrode. Representative 2D projections comparing peak-to-trough (amplitude; A) and voltage at a specified time (V) between tetrode channels are shown. Each colour represents a different BLA neuron. B, C, and D are spike waveforms of clustered spikes in A. Waveforms recorded from three channels from a single tetrode are shown. The smoothed lines on the right are the average waveforms. (Right) Electron microscopy picture of a 4 twisted wire electrode (scale bar 10 microns).

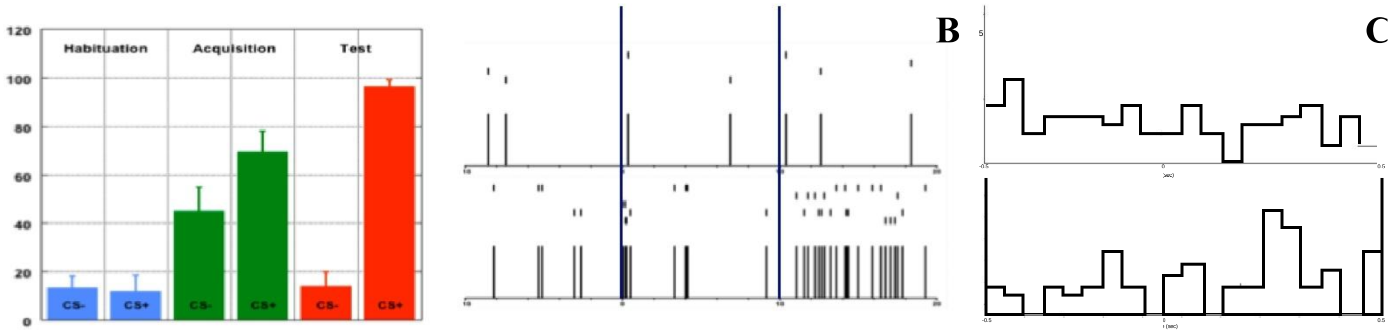


Figure 2. Percentage of freezing time (A) in the 3 phases of an auditory fear conditioning protocol (CS white noise or 7.5kHz tone, US: 0.5mA; 0.5s; habituation 12 presentations, acquisition 7 presentations, test 10 presentations one day after). Raster plot (B) of all acquisition trial for CS- (upper panel) and CS+ (lower panel) of one experiment, peristimulus time histogram shown under raster plots show the delayed response to the US. CS duration are represented by the 2 blue lines. Peristimulus time histogram (C) z-scored, aligned to the onset of the CS for the acquisition phase of the conditioning (CS-, upper trace; CS+, lower trace).

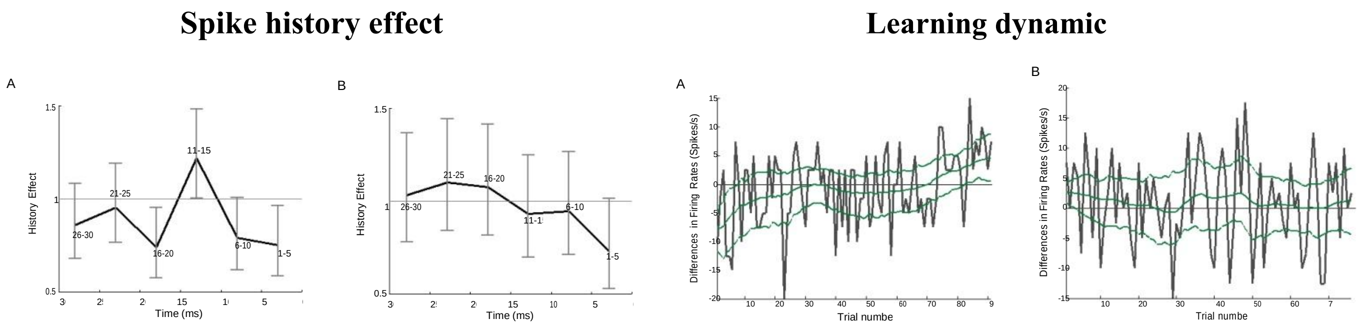


Figure 3. **Spike history effect**; SS-GLM estimates of the effect of recent spike history on current spike rate for A. CS+ trials, and B. CS- trials. The black line is the SS-GLM estimate. Grey bars are 95% CI. Positive modulation of the current spike rate is seen with history effect > 1; negative modulation of spike rate is seen with history effect < 1. The spike history in the preceding 11-15 ms positively modulated the current spike rate (95% CI: 1.004-1.483). **Learning Dynamic**. Change in firing rate difference between the 500-900 ms post-stimulus interval and the 100-500 ms post-stimulus interval across (A). CS+ trials, and (B). CS- trials. The difference is the 500-900 ms rate minus the 100-500 ms rate. The grey lines show the differences in firing rate for each trial. The solid green line shows the SS-GLM estimate of the difference in firing rate. The dotted green lines are the 95% CI for the SS-GLM estimate. There was a significant increase in the difference for the CS+ trials ($p < 0.004$).

We are also studying changes in neuronal activity at the network level (within or between brain regions) by measuring the correlation of firing between pairs of neurons (Figure 4) to then relate these changes against behavior.

In separate experiments we studied position related neuronal activity in the hippocampus (Figure 5), in accordance with previously published findings we observed place fields, which are zones of the foraging area where certain neurons are active. This activity is specific to the context in which the recording is performed, hence when the context is altered over a certain level the place cells show a different location specific firing.

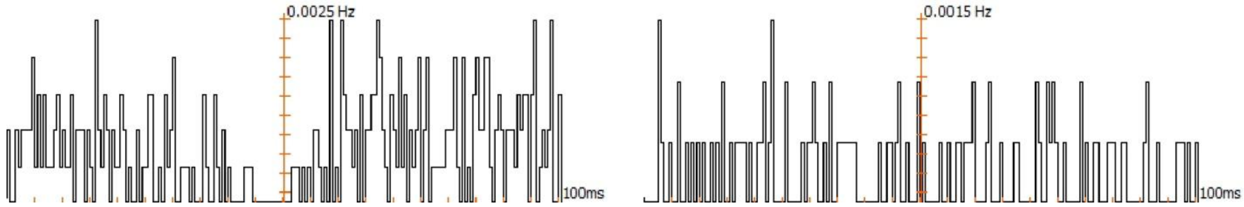


Figure 4. Cross-correlogram of neuronal activity recorded simultaneously within the same brain region during a learning task. Left: activity of one cell decreases in the 20 ms preceding spikes from the reference cell. Right: no specific pattern seems to link the activity of the 2 cells analyzed.

Navigation related memory formation is studied in rats using multi-unit recording implanted into both the amygdala and the hippocampus during acquisition and recall of a spatial task, active place avoidance (figure 6). An animal is placed in a cylindrical rotating arena and receives a mild footshock every time it enters an unmarked quadrant (60 degrees). The orientation cues are kept to a minimum to force the animal to hold a representation of space to avoid shocks, giving us the opportunity to study short term memory representation by neuronal activity. The same experiments are conducted during the 'recall session' (no shock) to study long term memory. For each part of this experiment we are also using place field mapping to investigate how space representation changes throughout training and how this neural activity is related to these changes.

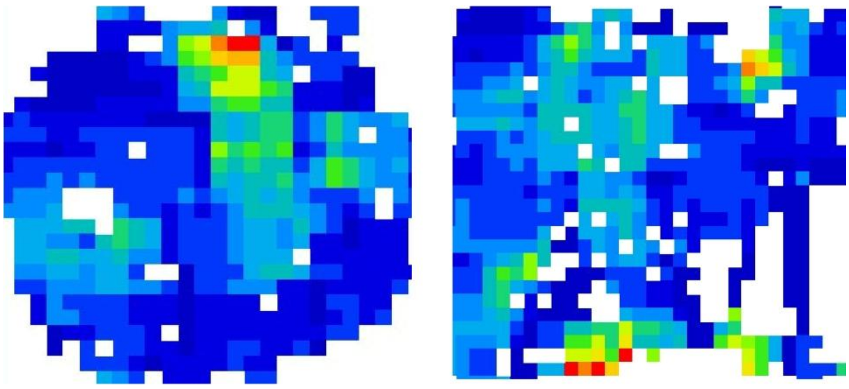


Figure 5. The same single neuron's activity was recorded in CA1 hippocampus region and mapped onto its foraging space from two different environment (0.72 sqm circular arena, left; 1.0 sqm square platform, right; colour coded activity: blue, place visited no activity; red 3.3 Hz left, 5Hz right).

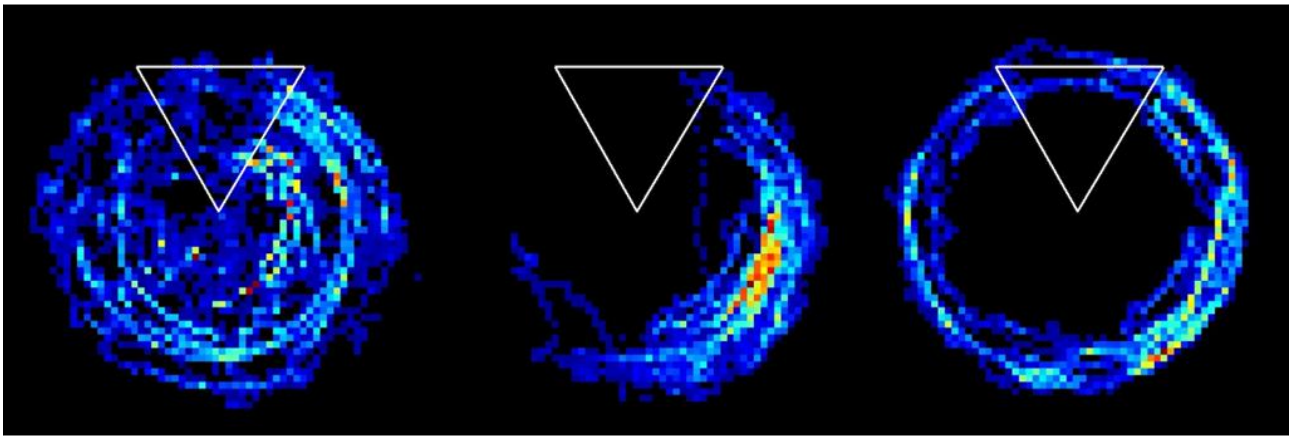


Figure 6: Colour coded place preference recorded during the habituation (left), training (middle) and retention test (no shock, right) during an active avoidance task (blue to red gradient indicates an increase in presence time). Shock intensity 0.2 mA, rotation 1 rpm counter clock-wise. A preference for the same "safe zone" is observed during the acquisition and test trials. This indicates that the rat held a representation of its position in space relative to the shock zone (an unmarked 60 deg quadrant at the top of the arena).

Ongoing Collaborative Research

Action potential waveform is not a reliable tool for spike sorting in collaboration with Thinking Systems' colleagues Peter Stratton and Allen Cheung.
Dorso ventral representation of place fields in CA3 in collaboration with Thinking Systems' colleague Chris Nolan.
Idiothetic navigation for early Alzheimer disease diagnostic in collaboration with Adam Hamelin (Coulson laboratory, QBI).

Publications

Crane, J.W.*, Windels, F.,* Sah, P. (2009) Oscillations in the basolateral amygdala: aversive stimulation is state dependent and resets the oscillatory phase. *Journal of Neurophysiology* 102: 1379-1387.
Windels, F.*, Crane, J.W.,* Sah P. (2010) Inhibition dominates the early phase of up-states in the basolateral amygdala. *Journal of Neurophysiology*. doi:10.1152/jn.00531.

* Authors contributed equally to the work.

Papers in Preparation

Martin, T., Windels, F. RatTrack, software based video analysis for learning and memory experiment. (in preparation).
Stratton, P., Cheung, A., Kiyatkin, E.A., Wiles, J., Sah, P., Windels, F. Action potential waveform consistency between neurons limits spike sorting accuracy. (in preparation).

Conference Poster

Brain Plasticity Symposium, (2010) Queensland Brain institute.
Australian Neuroscience Society meeting, (2010) Sydney.

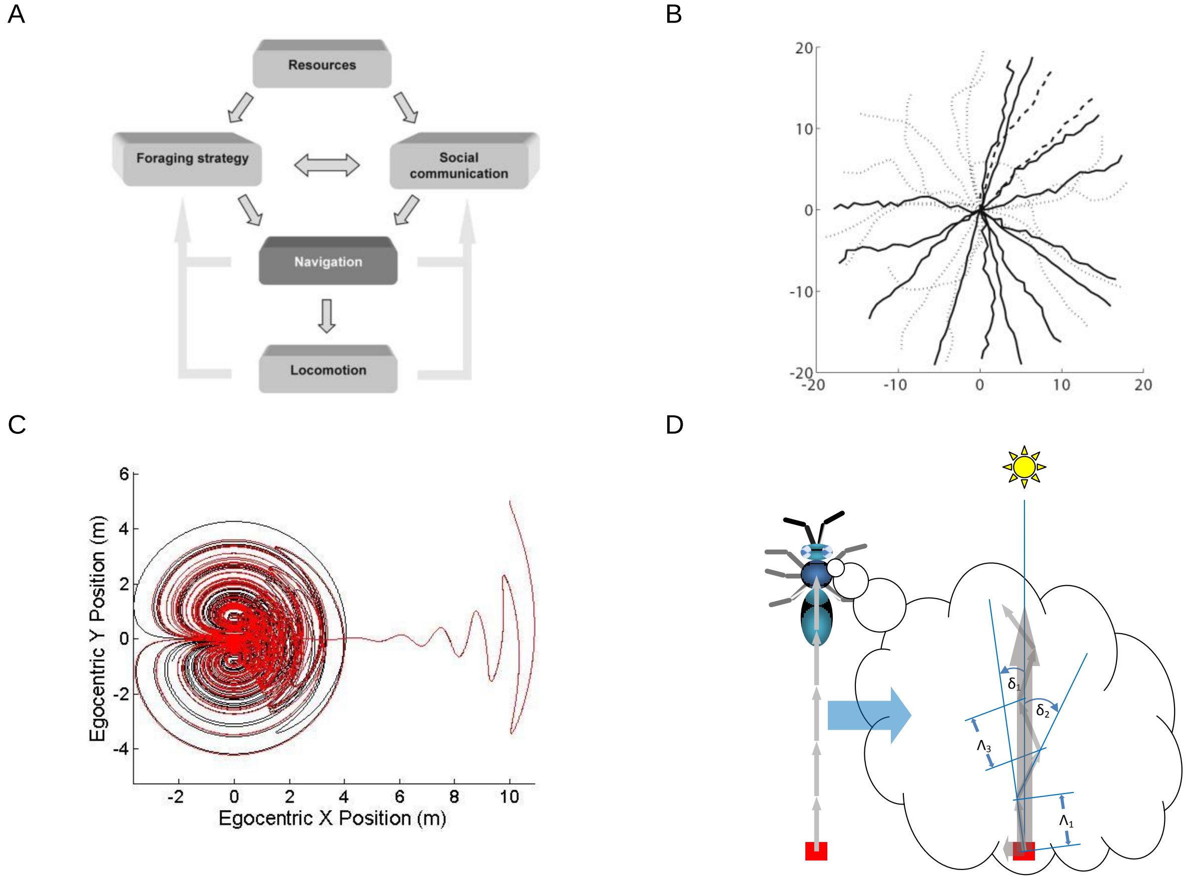
Laboratory Visits

June 2009, Visit to Matthew Wilson laboratory, Picower institute, MIT.
July 2009, Gordon conference, Neural circuit and plasticity, Newport.

Mathematical and Computational Theory of Animal Navigation

Allen Cheung

Navigation is an umbrella term which encompasses a wide range of sensorimotor and information processing tasks, many of which are still poorly defined or understood. A primary goal of theme 2b is to develop a theoretical understanding of the underlying principles common to all navigating agents, animal or robot. To achieve this goal it has been necessary to dissect navigational tasks into their most basic components, to understand the information required to solve those tasks, to use those mechanistic building blocks to generate complex biomimetic behaviours, and to see whether sophisticated methods can pick the correct building blocks from observed behaviour.



A. Schematic representation of information flow during social insect foraging. In this scheme, navigation (medium range) directly controls locomotion. In turn, higher level commands and strategies direct the navigation system. B. Graphical example of an unknown mixture of simulated (unbiased) idiothetic and allothetic directed walks (IDWs and ADWs) with varying magnitudes of random angular displacement errors, and unknown axes of intended locomotion. In this example, the decision algorithm was correct 28 out of 30 times (ADWs = solid lines, IDWs = dotted lines), being unable to decide in the remaining two (dashed lines). C. Computer simulated PI (path integration) homing and searching trajectory expressed in egocentric coordinates, showing damped oscillatory behaviour and chaotic point attractors. D. A schematic illustration of the mapping of a straight trajectory in real space to a neural representational space. This is an example of an allocentric static vectorial PI system, the only noise-tolerant class of PI systems.

Ongoing Collaborative Research

1. Collaboration with D. Ball, M. Milford

Blind Bayes in a box – computer simulation and robotic implementation of Bayes-optimal navigation in confined spaces under a variety of conditions, particularly in the absence of visual cues. We investigate whether the observed instability in rodent head direction system in darkness is theoretically compatible with a stable representation of place. (Manuscript in preparation.)

2. Collaboration with D. Angus, J. Wiles

Conceptual navigation – concept mapping algorithms are used to generate graphs from view-similarity matrices, which are compared to ground-truth spatial layout. This is carried out in strictly controlled virtual environments, simulating those of real experiments, in order to understand the relationship between metric space and different visual environments. Metrics are developed to quantify that relationship so different experimental arenas may be compared in a quantitatively meaningful way, particularly with respect to spatial navigation tasks.

3. Collaboration with P. Stratton, F. Windels

Spike waveform analysis – in vivo extracellular action potential waveforms from awake and anaesthetized rats, with and without local pharmacological treatment, from various brain regions are analysed and compared. Waveform variability is quantified to determine the likely error rate when standard classification techniques are used.

4. Collaboration with T. Luu, D. Ball, M. Srinivasan

Honeybee flight behaviour in virtual reality – the evidence from simple tethered experiments seem to differ from free flight with respect to the functional class of EMDs (elementary motion detectors) used by flying insects. Using the existing setup, it is possible to visually simulate free flight, whilst tethered. Since the abdominal pitch has been shown to vary according to visually-perceived forward speed, the pitch may be used to gauge the perceived speed in the presence of visual patterns of different spatial and temporal frequencies.

5. Collaboration with G. Goodhill, M. Srinivasan

Distance travelled without a compass – animals do not always have access to stable directional cues (i.e., a compass) but it may be very difficult to ascertain experimentally, particularly since the animal's intended travel direction may vary over short segments of the journey. However, the average radial distance travelled varies depending on whether internal or external directional cues are used. A simple formula to calculate the expected radial displacement has eluded researchers, but simple accurate approximations have been developed.

6. Collaboration with J. Reinhard

Key odorants – odours are important for guidance and localization in animal navigation. Yet it remains unclear how complex scent mixtures are processed and interpreted by the nervous system. Here, human subjects are asked to grade the odour similarity of constituent compounds to the mixture source. A novel theory of 'key odorants' has been developed to explain the data, which has implications for theories of olfactory learning, as well as applications in food and wine industries. (Manuscript in preparation.)

Publications

PhD Thesis title: Theory and neural network models of insect navigation. PhD (Neuroscience) awarded 21 Dec 2007.

Vickerstaff, R., Cheung, A. (2010) "Which coordinate system for modelling path integration," *Journal of Theoretical Biology*. 263: 242-261.

Cheung, A. (2010) "The fourth moment of the radial displacement of a discrete correlated/persistent random walk," *Journal of Theoretical Biology.* 264: 641-644.

Cheung, A., Vickerstaff, R. (2010) "Finding the way with a noisy brain," *PLoS Computational Biology* (in press).

Cheung, A. (2009) "Mathematical and neural network models of medium range navigation during social insect foraging," In: *Jarau and Hrncir* (eds.) Food Exploitation by Social Insects: Ecological, Behavioral, and Theoretical Approaches. Taylor & Francis Group LLC.

Garratt, M., Cheung, A. (2009) "Obstacle avoidance in cluttered environments using optic flow," Australasian Conference on Robotics and Automation (ACRA).

Cheung, A., Stürzl, W., Zeil, J., Cheng, K. (2008). "The information content of panoramic images II: View-based navigation in nonrectangular experimental arenas," *Journal of Experimental Psychology: Animal Behaviour Processes.* 34(1): 15-30.

Cheung, A. (2008) "From behaviour to brain dynamics," in: Marinaro M., Scarpetta S. and Yamaguchi Y. (Eds) Dynamic Brain – from Neural Spikes to Behaviors, Lecture Notes in *Computer Science*, vol 5286, pp91-95. Springer Berlin / Heidelberg.

Cheung, A., Zhang, S.W., Stricker, C., Srinivasan, M.V. (2008) "Animal navigation: General characteristics of directed walks," *Biological Cybernetics*. 99: 197-217.

Stürzl, W., Cheung, A., Cheng, K., Zeil, J. (2008). "The information content of panoramic images I: The rotational errors and the similarity of views in rectangular experimental arenas," *Journal of Experimental Psychology: Animal Behaviour Processes*. 34(1): 1-14.

Submissions

Luu, T., Cheung, A., Ball, D., Srinivasan, M.V. "Honeybee flight: A novel 'streamlining' response," Journal of Experimental Biology (under revision).

Conference Abstracts or Poster

Luu, T., Cheung, A., Ball, D., Srinivasan, M.V. (2010) "Honeybee flight: A novel 'streamlining' response," Poster: 9th International Congress of Neuroethology.

Related Activities

Invited speaker at the 7th ACEVS-CVS Summer School on Animal Navigation (1st-5th Dec 2008).

Speaker at ANZIAM: 45th Applied mathematics Conference (1st-5th Feb 2009).

Main organizer of the 8th ACEVS-CVS Summer School on Animal Navigation (23rd-27th Nov 2009), held for the first time at UQ.

Invited speaker at the 9th International Congress of Neuroethology (2nd-7th Aug 2010, Spain).

International Links

14th Dec 2007 - Gatsby Computational Neuroscience Unit (visit with Peter Dayan), UCL (+ presentation).

15th Dec 2007 - Institute of Cognitive Neuroscience (visit with Neil Burgess), UCL.

Media Coverage

Commentator for New Scientist about new article:
Souman, J., Frissen, I., Sreenivasa, M., Ernst, M. (2009) "Walking straight into circles," Current Biology. 19: 1-5.
[http://www.newscientist.com/article/dn17658-we-cant-help-walking-in-circles.html]

Commentator for ABC Science about new article:
Lent, D., Graham, P. and Collett, T. (2010) "Image-matching during ant navigation occurs through saccade-like body turns controlled by learned visual features," Proceedings of the National Academy of Science USA 107(37): 16348-16353.
[http://www.abc.net.au/science/articles/2010/09/02/2997444.htm]

Supervision of students related to Thinking Systems

Benjamin Sinclair, TS Summer Scholar: "Deconstructing a squiggle".
Kieran McLean, TS Winter Scholar: "Boxed in".

Understanding the Dynamics and Function of Networks of Spiking Neurons

Peter Stratton

Project 1: In Vivo Spike Shape Analysis – collaboration with Francois Windels.

Spikes have been recorded from single neurons in awake, behaving animals. Some of the neurons were also subjected to pharmacological manipulation to, for example, increase excitability of the neural membrane or block inhibition. This is a unique dataset that enables characterisation of spiking dynamics in awake, behaving animals rather than in anesthetised animals or in slice preparations. Analysis of this dataset has shown strong dependence of spike amplitude on spiking rate for the majority of cells (see Figure 1) as well as spike shape changes for some cells.

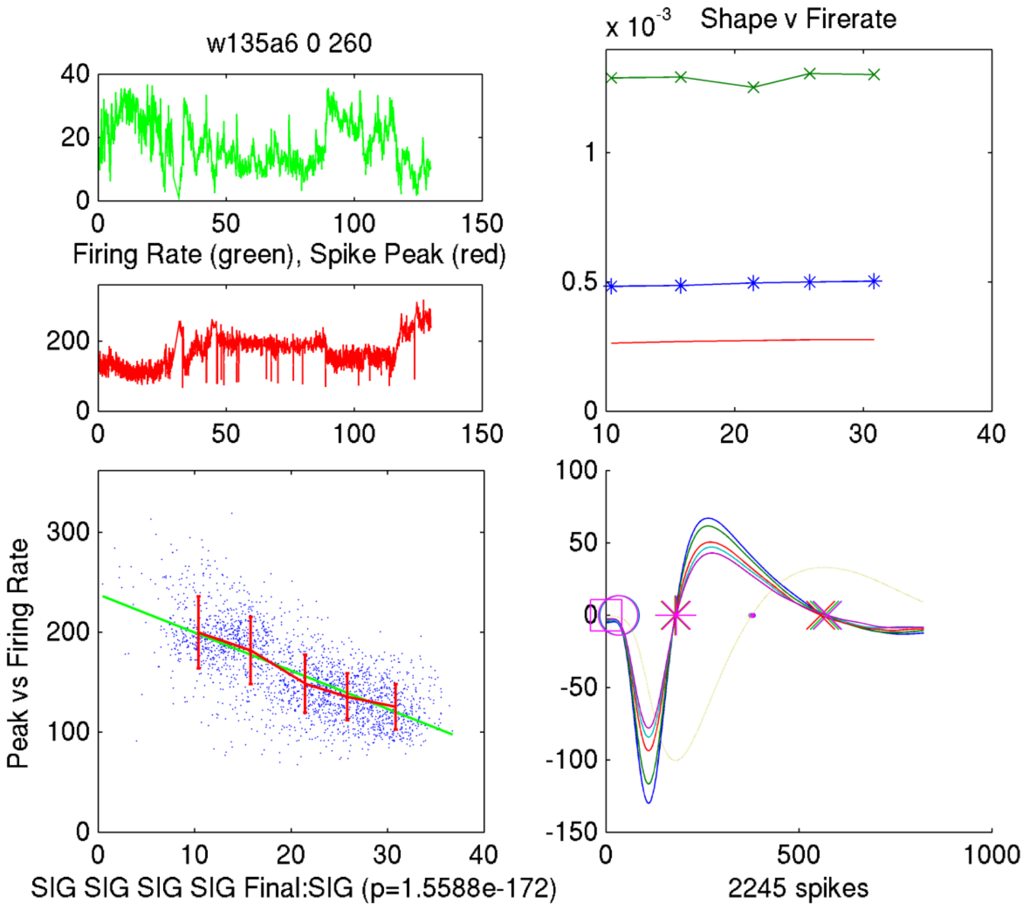


Figure 1: Spike amplitude is inversely correlated with firing rate. Top-left: Firing rate (green) and spike amplitude (red) shown over 130 s of recording. Bottom-left: Spike amplitude plotted against firing rate shows a clear inverse correlation (line of best fit – green; mean and std dev. – red). Top-right: Spike rise time (blue), fall time (green) and half width (red) in milliseconds, plotted against firing rate, show no significant change. Bottom-right: Average spike shapes plotted for low firing rates to high firing rates in five steps (blue, green, red, cyan and magenta) shows falling spike amplitude for higher firing rates.

The dataset is also unique because each recording clearly identifies a single recorded cell, allowing comparisons to be drawn between spike shapes of different neurons. The similarity of the spike shapes recorded from different neurons and the high level of noise that is typically present in neural recordings mean that spikes from different cells are likely to be misclassified (i.e. attributed to incorrect neurons) when doing normal multi-neuron recordings using single electrodes. We have calculated, for any given signal-to-noise ratio (SNR) and any given neural density, how likely misclassification is to occur. We have shown that neural recordings using single electrodes are highly likely to give erroneous results, with misclassification rates above 99% for many brain regions.

Project 2: Spike Timing Dependent Plasticity and Oscillations in Networks of Spiking Neurons

Complex activity in the brain is hypothesised to underlie its flexibility and sophisticated processing capability (i.e. higher cognitive function). This is particularly evident during periods of quiet relaxation when 10 Hz alpha waves are seen in many brain regions. This activity is associated with memory retrieval, planning, problem solving and day dreaming. Until now, it has not been possible to reproduce this sort of activity in a model of the brain; this is what we have been able to do. We are now investigating how modification of the synapses connecting the neurons (using Spike Timing Dependent Plasticity (STDP)) changes the network dynamics and how learning of spatiotemporal patterns of network activity can be achieved. Understanding how patterns can be stored in a network of spiking neurons is critical to understanding learning and memory in the brain.

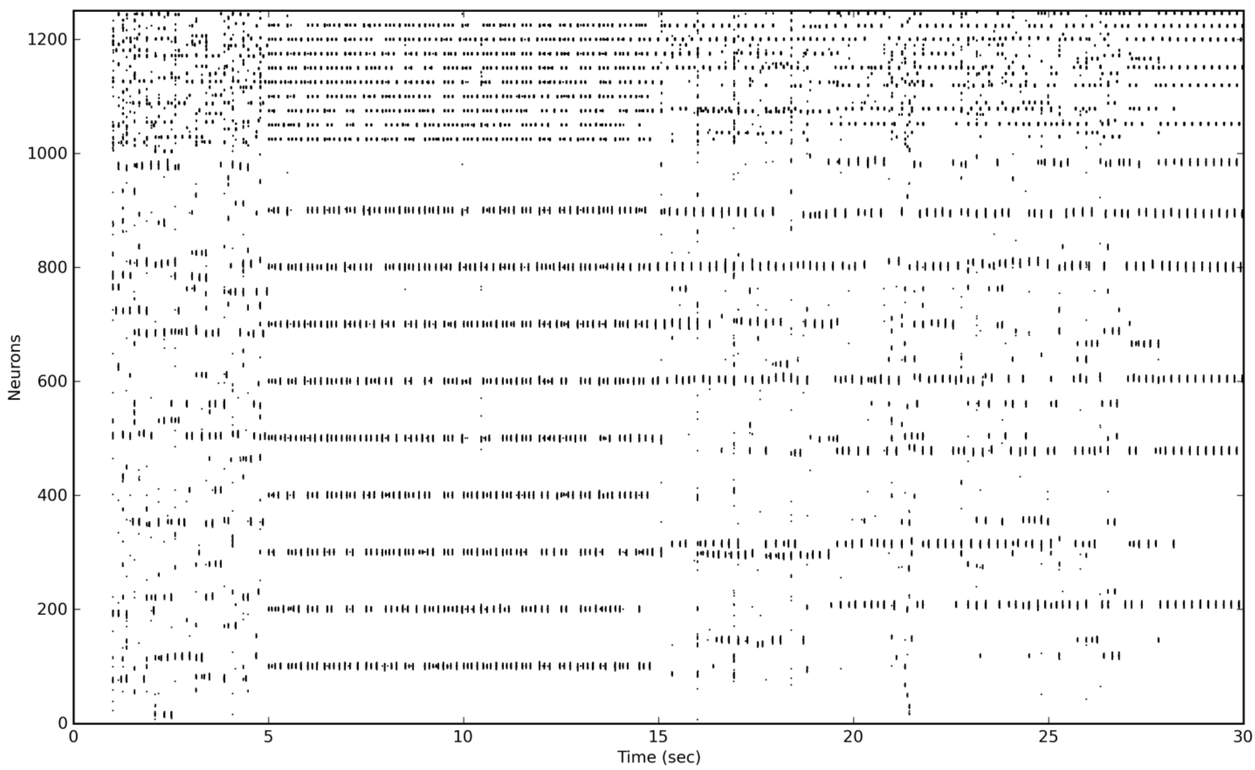


Figure 2: Patterns of activity can be learned in a network of spiking neurons. The network contains 1250 neurons (Y axis) and was simulated for 30 seconds (X axis). For the first 5 seconds of simulation the network operated in a random activity regime with no external input, after which a fixed activity pattern was held for 10 seconds through input provided by external connections. When the external input was released at 15 seconds time, the observed pattern is partially reproduced in the ongoing network activity from 15 to 30 seconds.

Project 3: Calibration of Head Direction Networks on Robots

Neurons have been discovered in the brains of mammals that are active only when the animal is in a certain place in its environment, and others when the animal is facing a certain direction, effectively providing a brain-based map and compass. Understanding how such specific functions arise and are controlled in the brain can assist in revealing how the brain functions in general and how these functions can go awry in cases of brain injury and disease. We have modelled the brain network that contains the neurons that represent head direction in the mammalian brain (see Figure 3), and have shown how this network can be calibrated on a mobile robot, through feedback from the world, when the robot follows specific movements that many infant mammals perform. This work advances our understanding of the neural systems involved in motion tracking and the representation of space, links these systems to specific developmental behaviours and motor deficits, and further demonstrates how biological processes can afford practical solutions to engineering problems.

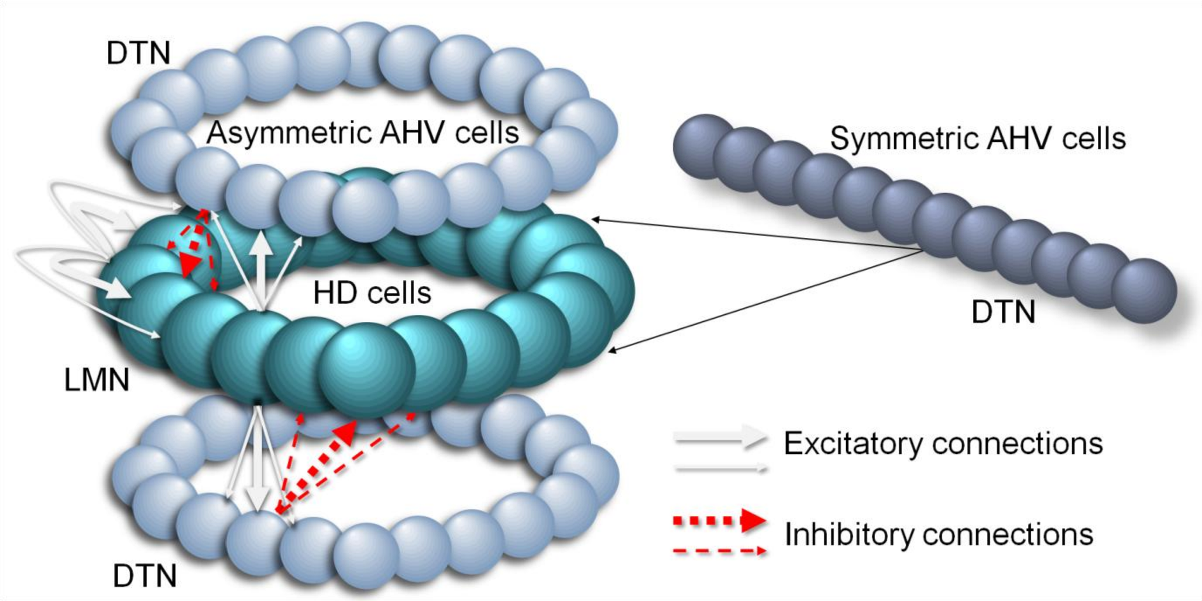


Figure 3: Head direction network. Head direction (HD) cells excite their close neighbours strongly and more distant neighbours less strongly, and this self-excitation creates the HD activity. These excitatory connections are calibrated to allow the HD system to accurately represent head direction as the animal or robot moves. The HD cells are also inhibited by the asymmetric Angular Head Velocity (AHV); the overall efficacy of this inhibition is also calibrated. DTN: Dorsal tegmental nucleus, LMN: Lateral mammillary nucleus.

Ongoing Collaborative Research

Collaborated with Michael Milford and Gordon Wyeth: Calibrating spiking head direction networks on robots with long-term deployments, for example in factory and warehouse delivery tasks, where on-going calibration is required due to mechanical wear and damage accrued over long timeframes.

Collaborated with Francois Windels and Allen Cheung: Continued analysis of the unique neural recording datasets from awake, behaving animals.

Collaborated with David Ball and Chris Nolan: Controlling Braitenberg vehicles with spiking neural networks – how do the temporal dynamics of spiking networks assist in the temporal organisation of embodied behaviour?

Publications

Stratton, P., Wiles, J. (2010) Self-sustained non-periodic activity in a network of spiking neurons: The contribution of local and long-range connections and dynamic synapses. *NeuroImage* 52: 1070-1079.

Stratton, P., Wyeth, G.F. and Wiles, J. (2010) Calibration of the Head Direction Network: a role for Symmetric Angular Head Velocity cells. *Journal of Computational Neuroscience* 28: 527-538.

Wiles, J., Ball, D., Heath, S., Nolan, C., Stratton, P. (2010) Spike-time robotics: a rapid response circuit for a robot that seeks temporally varying stimuli. To appear In *Australian Journal of Intelligent Information Processing Systems.*

Stratton, P., Wiles, J. (2010) Complex Spiking Models: A Role for Diffuse Thalamic Projections in Complex Cortical Activity. To appear In Springer LNCS.

Stratton, P., Milford, M., Wiles, J., Wyeth, G.F. (2009) Automatic Calibration of a Spiking Head-Direction Network for Representing Robot Orientation. In Proceedings of the Australasian Conference on Robotics and Automation, Sydney, Australia. 8 pages.

Stratton, P., Wiles, J. (2008) Comparing Kurtosis Score to Traditional Statistical Metrics for Characterizing the Structure in Neural Ensemble Activity. In M. Marinaro et al., editors, Dynamic Brain – from Neural Spikes to Behaviors, Springer LNCS V 5286, 115-122.

Conference Abstracts or Posters

Stratton, P., Wiles, J. A role for symmetric head-angular-velocity cells: Tuning the head-direction network. Frontiers in Systems Neuroscience, 2009 (COSYNE'09).

Stratton, P. Poster presentation at Complex (2007) (Complex Systems conference), Gold Coast, Australia, July 2-5, 2007.

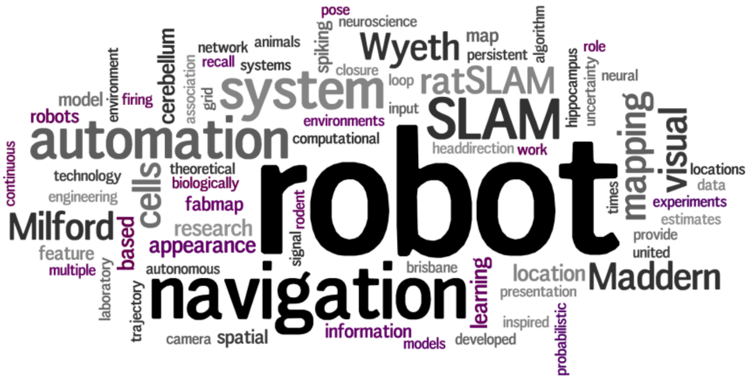
Related Activities

Invited to talk at the "Dynamic Brain: From Neural Spikes to Behaviour" workshop, Sicily, Italy, Dec 5-12, 2007

"Co-organiser of the "Summer of Spikes" summer school on Computation in Spiking Neural Networks, Dec 2009 – Feb 2010."

International Links

Visited and presented at University College London, December 2007. "Comparing Kurtosis Score to Traditional Statistical Metrics for Characterizing the Structure in Neural Ensemble Activity".



Theme 3: Biologically Inspired Robot Navigation

Robotics plays two roles in this project. Firstly, robots are serving as mechanisms for embodying the neurocomputational models of navigation in real physical spaces, with focus on the biological plausibility of the models. In the second role, the neurocomputational models are serving as inspiration for frontier technologies for sensing and navigation in autonomous robots. The focus in the second role is on engineering effectiveness.

Project Members

Theme Leader	Gordon Wyeth
Chief Investigators	Janet Wiles, John O'Keefe, Michael Arbib, Mandyam Srinivasan
Research Fellow	Michael Milford
PhD Students	Christopher Nolan, William Maddern.
Research Assistant	William Maddern
Collaborators	In Thinking Systems: Peter Stratton, David Ball, Allen Cheung. In ITEE: Ruth Schulz
Research Experience Students	Daniel Clarke (2009-10)

Brain-Based Robot Navigation

Michael Milford

The core Theme 3 research topic of brain-based robot navigation has produced significant research outcomes as well as driving collaborative research with computational neuroscientists. Major robotic research outcomes include breakthrough results in visual SLAM (Simultaneous Localization And Mapping) in very large environments as well as in long term persistent robot navigation, both achieved using the brain-based RatSLAM robot navigation system. Major neuroscience research outcomes include the development and publication of a new theory of how grid cells in the rodent brain may help with navigation in perceptually ambiguous environments. Theme research has driven collaborative work with computational neuroscientists working on functional neural learning models, spiking head-direction models implemented on robots, and with roboticists developing a new robotic *iRat* platform. Here we present three of the major research outcomes of the theme.

2010 – Solving Navigational Uncertainty using Grid Cells on Robots

To successfully navigate their habitats, many mammals use a combination of two mechanisms, path integration and calibration using landmarks, which together enable them to estimate their location and orientation, or pose. In large natural environments, both these mechanisms are characterized by uncertainty: the path integration process is subject to the accumulation of error, while landmark calibration is limited by perceptual ambiguity. It remains unclear how animals form coherent spatial representations in the presence of such uncertainty. Navigation research using robots has determined that uncertainty can be effectively addressed by maintaining multiple probabilistic estimates of a robot's pose. We showed how conjunctive grid cells in dorsocaudal medial entorhinal cortex (dMEC) may maintain multiple estimates of pose using a brain-based robot navigation system known as RatSLAM. Based both on rodent spatially-responsive cells and functional engineering principles, the cells at the core of the RatSLAM computational model have similar characteristics to rodent grid cells, which we demonstrate by replicating the seminal Moser experiments. We applied the RatSLAM model to a new experimental paradigm designed to examine the responses of a robot or animal in the presence of perceptual ambiguity (see Figure 1). Our computational approach enabled us to observe short-term population coding of multiple location hypotheses, a phenomenon which would not be easily observable in rodent recordings. We gathered behavioral and neural evidence demonstrating that the conjunctive grid cells maintain and propagate multiple estimates of pose, enabling the correct pose estimate to be resolved over time even without uniquely identifying cues. While recent research has focused on the grid-like firing characteristics, accuracy and representational capacity of grid cells, our results identify a possible critical and unique role for conjunctive grid cells in filtering sensory uncertainty. We anticipate our study to be a starting point for animal experiments that test navigation in perceptually ambiguous environments.

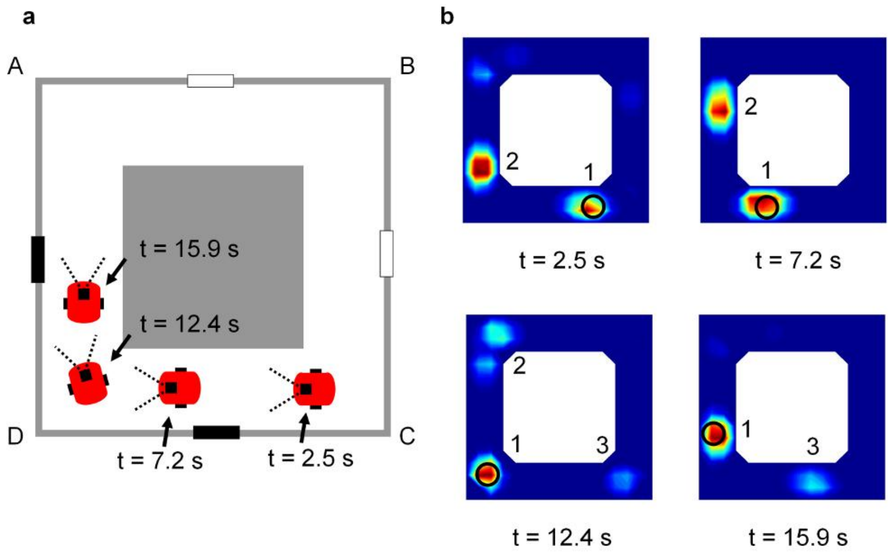


Figure 1. The actual robot pose and corresponding location estimates encoded by the ensemble grid cell firing. Each firing plot corresponds to various times after the robot was replaced at corner C facing D. (a) Schematic of the robot's pose corresponding to each of the four ensemble firing plots. (b) Location estimates as encoded by the weighted sum of the firing fields of all active cells at various times. The circle shows the robot's actual location. Cell firing initially (t = 2.5, 7.2 s) supported and maintained two approximately equal location estimates (1 and 2) – sighting the first black cue did not provide sufficient information to disambiguate the robot's location. After sighting of the second black cue (t = 12.4 s), cell firing resolved to code primarily for the correct location 1 – location estimate 2 disappeared (t = 15.9 s) and there was limited firing for a new location estimate 3.

2009 – Persistent Navigation and Mapping using a Biologically Inspired SLAM System

The challenge of persistent navigation and mapping is to develop an autonomous robot system that can simultaneously localize, map and navigate over the lifetime of the robot with little or no human intervention. Most solutions to the SLAM problem aim to produce highly accurate maps of areas that are assumed static. In contrast, solutions for persistent navigation and mapping must produce reliable goal-directed navigation outcomes in an environment that is assumed to be in constant flux. We investigated the persistent navigation and mapping problem in the context of an autonomous robot that performs mock deliveries in a working office environment over a two week period. The solution was based on the biologically inspired visual SLAM system, RatSLAM. RatSLAM performed SLAM continuously while interacting with global and local navigation systems, and a task selection module that selected between exploration, delivery, and recharging modes. The robot performed 1143 delivery tasks to 11 different locations with only one delivery failure (from which it recovered), travelled a total distance of more than 40 kilometres over 37 hours of active operation, and recharged autonomously a total of 23 times (see Figure 2).

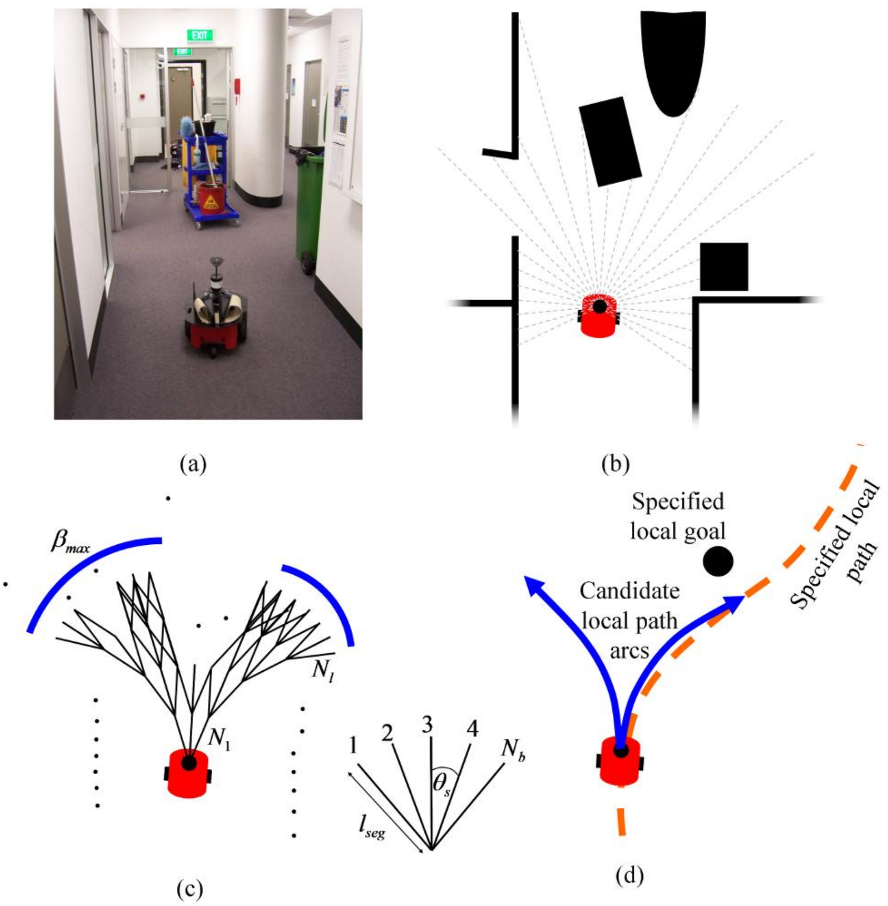


Figure 2. A photo of the robot in the environment during the experiments, and a schematic showing the local navigation process. (b) Laser and sonar scans (idealized and sparser than in reality) are converted into a (c) particle obstacle map. Branches from a tree search are grouped and converted into candidate path arcs (d) which are compared for closeness to either a specified local goal or path.

2008 – Mapping a Suburb with a Single Camera using a Biologically Inspired SLAM System

This work developed a biologically inspired approach to vision-only SLAM on ground-based platforms. The core SLAM system, dubbed RatSLAM, is based on computational models of the rodent hippocampus, and is coupled with a lightweight vision system that provides odometry and appearance information. RatSLAM builds a map in an online manner, driving loop closure and re-localization through sequences of familiar visual scenes. Visual ambiguity is managed by maintaining multiple competing vehicle pose estimates, while cumulative errors in odometry are corrected after loop closure by a map correction algorithm. We demonstrated the mapping performance of the system on a 66 kilometre car journey through a complex suburban road network. Using only a web camera operating at 10 Hz, RatSLAM generated a coherent map of the entire environment at real-time speed, correctly closing more than 51 loops of up to 5 kilometres in length (see Figure 3).

Figure 3. RatSLAM created an accurate street map of the entire suburb of St Lucia (66 km of driving) using only the sensory input from a web camera mounted on top of the car.

Ongoing Collaborative Research

Calibrating Spiking Head-Direction Networks on Robots

Stratton, P., Milford, M.J., Wyeth, G.F., Wiles, J.

Combining spiking head-direction networks, theoretical models of head-direction cells and experiments on robots to provide insights into biology. Calibrating spiking head direction networks on robots with long-term deployments, for example in factory and warehouse delivery tasks, where on-going calibration is required due to mechanical wear and damage accrued over long timeframes. Involves the University of Queensland and the Queensland University of Technology.

Blind Bayes in a Box: Rat and Robot Navigation in the Dark

Cheung, A., Ball, D., Milford, M.J., Wyeth, G.F., Wiles, J.

Developing algorithms for calibrating navigation in sensory deprived environments such as in darkness through experimentation on a range of robotic platforms. Involves the University of Queensland and the Queensland University of Technology

A Navigating Rat Animat

Ball, D., Heath, S., Milford, M.J., Wyeth, G.F., Wiles, J.

Development of algorithms to provide mapping and navigation capabilities for a robotic iRat. Development of adaptive exploration and navigation behaviours for a robotic iRat. Involves the University of Queensland and the Queensland University of Technology.

A Flying Rat-Brained Robot

Milford, M.J., Schill, F., Corke, P., Mahony, R., Wyeth, G.F.

Developing a visual SLAM system for mapping and navigation on micro aerial vehicles flying in cluttered indoor and outdoor environments. Involves the Queensland University of Technology and the Australian National University.

Publications

Books

Milford, M.J. (2008) *Robot Navigation From Nature*, Springer Tracts in Advanced Robotics, Springer-Verlag.

Journals

Milford, M.J., Wiles, J., Wyeth, G.F.(2010) “Solving Navigational Uncertainty using Grid Cells on Robots”, accepted to *PLoS Computational Biology*, in press.

Milford, M.J., Wyeth, G.F. (2010) "Persistent Navigation and Mapping using a Biologically Inspired SLAM System", *The International Journal of Robotics Research* 29: 1131

Milford, M.J., Wyeth, G.F. (2010) "Hybrid Robot Control and SLAM for Persistent Navigation and Mapping", *Robotics and Autonomous Systems*. Vol. 58, Issue 9, 1096-1104

Milford, M.J., Wyeth, G.F. "Mapping a Suburb with a Single Camera using a Biologically Inspired SLAM System", IEEE Transactions on Robotics, 24 (5), pp. 1038-1053, 2008.

Milford, M.J. "From Rats to Robots: Engineering a Functional Biomimetic Navigation System", *Journal and Proceedings of The Royal Society of New South Wales,* 141 (1-2), pp. 3-25, 2008.

Milford, M.J., Schulz, R., Prasser, D., Wyeth, G.F., Wiles, J. “Learning Spatial Concepts from RatSLAM Representations”, *Robotics and Autonomous Systems*, pp. 403-410, 2007.

Nolan, C.R., Wyeth, G.F., Milford, M.J., Wiles, J. (2010) “The Race to Learn: Spike Timing and STDP Can Coordinate Learning and Recall in CA3”, *Hippocampus*. DOI: 10.1002/hipo.20777

Wyeth, G.F., Milford, M.J. (2009) “Spatial Cognition for Robots: Robot Navigation from Biological Inspiration”, IEEE Robotics and Automation Magazine, 16 (3).

Submissions

Stratton, P., Milford, M.J., Wyeth, G.F., Wiles, J. (2010) “Infant Mammal Movement Strategies Efficiently Calibrate a Spiking Head-Direction Network”, submitted to *PLoS Computational Biology*.

Milford, M.J., Schill, F., Corke, P., Mahony, R., Wyeth, G.F., (2011) “Aerial SLAM with a Single Camera using Visual Expectation”, submitted to the *IEEE International Conference on Robotics and Automation*, Shanghai, China.

Milford, M.J and Wyeth, G.F. (2010) “Improving Recall in Appearance-Based Visual SLAM using Visual Expectation”, submitted to the *Australasian Conference on Robotics and Automation*, Brisbane, Australia.

Maddern, W. P., Milford, M.J. and Wyeth, G.F. (2011) "Continuous Appearance-based Trajectory SLAM", submitted to the *IEEE International Conference on Robotics and Automation*, Shanghai, China.

Maddern, W. P., Milford, M.J., Wyeth, G.F., (2011) "Predicting Feature Disappearance for Extrapolation of Observations in Appearance-based SLAM", submitted to the *IEEE International Conference on Robotics and Automation*, Shanghai, China.

Maddern, W. P., Milford, M.J., Wyeth, G.F. (2010) "Loop Closure Detection on a Suburban Road Network using a Continuous Appearance-based Trajectory", submitted to the *Australasian Conference on Robotics and Automation*, Brisbane, Australia.

Schulz, R., Glover, A., Milford, M.J., Wyeth, G.F., Wiles, J. (2011) "Lingodroids: Studies in Spatial Cognition and Language", submitted to the *IEEE International Conference on Robotics and Automation*, Shanghai, China.

Refereed Conference Papers and Book Chapters

Milford, M.J., Wyeth, G.F. (2008) "Single Camera Vision-Only SLAM on a Suburban Road Network", in proceedings of the IEEE International Conference on Robotics and Automation, Pasadena, United States.

Milford, M.J., Wyeth, G.F. (2007) "Spatial Mapping and Map Exploitation: a Bio-Inspired Engineering Perspective", Springer Lecture Notes in Computer Science (LNCS).

Milford, M.J., Wyeth, G.F. (2007) "Featureless Vehicle-Based SLAM with a Consumer Camera", in proceedings of the Australasian Conference on Robotics and Automation, Brisbane, Australia.

Ball, D., Heath, S., Milford, M.J., Wyeth, G.F., Wiles, J. (2010) "A Navigating Rat Animat", in proceedings of the International Conference on Artificial Life, Odense, Denmark.

Glover, A.J., Maddern, W. P., Milford, M.J., Wyeth, G.F. (2010) "FAB-MAP + RATSLAM: Appearance-based SLAM for Multiple Times of Day", in proceedings of the IEEE International Conference on Robotics and Automation, Anchorage, Alaska.

Maddern, W. P., Glover, A.J., Milford, M.J., Wyeth, G.F. (2009) "Augmenting RatSLAM using FAB-MAP-based Visual Data Association", in proceedings of the Australasian Conference on Robotics and Automation, Sydney, Australia.

Oates, R., Milford, M.J., Wyeth, G.F., Kendall, G., Garibaldi, J. M. (2009) "The Implementation of a Novel, Bio-Inspired, Robotic Security System," in proceedings of the IEEE International Conference on Robotics and Automation, Kobe, Japan.

Stratton, P., Milford, M.J., Wiles, J., Wyeth, G.F. (2009) "Automatic Calibration of a Spiking Head-Direction Network for Representing Robot Orientation", in proceedings of the Australasian Conference on Robotics and Automation, Sydney, Australia.

Wyeth, G.F., Milford, M.J., Schulz, R., Wiles, J. (2010) "The RatSLAM project: robot spatial navigation", in Neuromorphic and Brain-Based Robotics, Cambridge University Press, in press.

Wyeth, G.F., Milford, M.J. (2009) "Towards Lifelong Navigation and Mapping in an Office Environment", in proceedings of the International Symposium of Robotics Research.

Patents / Commercialisation

Milford, M.J., Wyeth, G.F. (2009) "Method and Algorithm for Creating a Navigable Spatial Map of Panoramic Images from Video", filed provisionally.

Related Activities

Local Chair and Paper Committee Member, 2010 Australasian Conference on Robotics and Automation, Brisbane, Australia.

Attended the Champalimaud Neuroscience Hippocampus and Navigation Symposium, Lisbon, Portugal, 2008.

Presentations at the following conferences:

2003 Australasian Conference on Robotics and Automation (Brisbane, Australia)

2004 International Conference on Robotics and Automation (New Orleans, United States)

2005 Australasian Conference on Robotics and Automation (Sydney, Australia)

2006 International Conference on Robotics and Intelligent Systems (Beijing, China)

2007 Conference on Spatial Information Theory (Melbourne, Australia)

2007 Australasian Conference on Robotics and Automation (Brisbane, Australia)

More than a dozen school and community presentations on robotics and neuroscience.

Seminars, Tutorials, Courses Presented

February 2010, “Using Models of the Rodent Hippocampus for Robot Navigation”, invited presentation at the Faculty of Engineering and Information Technology, Australian National University, Canberra, Australia

February 2009: Invited presentation at the Computational Neuroscience course run at the Queensland Brain Institute, Brisbane, Australia.

March 2008: Presentation at the Champalimaud Neuroscience Hippocampus and Navigation Symposium, Lisbon, Portugal.

March 2008: Presentation to the laboratory of Professor Edvard Moser and May-Britt Moser, Kavli Institute for Systems Neuroscience and Centre for Biology for Memory, Norwegian University of Science and Technology, Trondheim, Norway.

March 2008: Presentation at the laboratory of Professor John O’Keefe and Professor Neil Burgess, University College London Institute of Cognitive Neuroscience, London, United Kingdom.

March 2008: Presentation to the laboratory of Dr Andrew Davison, Department of Computing, Imperial College London, London, United Kingdom.

International Links

Visits from Associate Professor Robert Mahony, Faculty of Engineering and Information Technology, Australian National University, Canberra, Australia. February and October 2010.

Visit to the laboratory of Associate Professor Robert Mahony, Faculty of Engineering and Information Technology, Australian National University, Canberra, Australia. February 2010.

Visit to the laboratory of Professor Edvard Moser and Professor May-Britt Moser, Kavli Institute for Systems Neuroscience and Centre for Biology for Memory, Norwegian University of Science and Technology, Trondheim, Norway, March 2008.

Visit to laboratories of Professor Neil Burgess and Professor John O’Keefe, University College London Institute of Cognitive Neuroscience, London, United Kingdom, March 2008.

Visit to the laboratory of Dr Andrew Davison, Department of Computing, Imperial College London, March 2008.

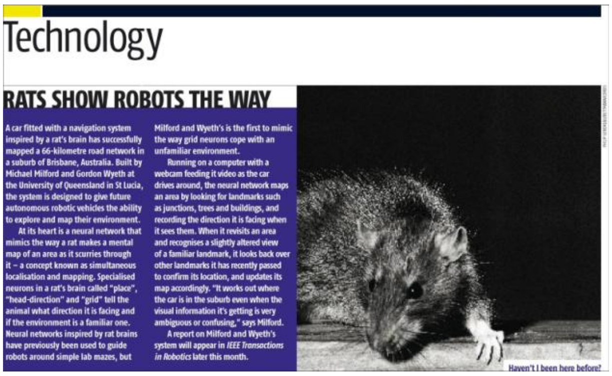
Visit to the laboratory of Professor Keith Downing, Department of Computer and Information Sciences, Norwegian University of Science and Technology, March 2008.

Visit from Dr Robert Oates, School of Computer Science and IT, University of Nottingham, Nottingham, United Kingdom, 2008.

Media Coverage

19 February, 2009, TV: ABC Catalyst.
http://www.abc.net.au/catalyst/stories/2494845.htm

October 2008, Magazine: New Scientist Magazine.
http://www.newscientist.com/article/mg20026765.300-rat-brains-show-robots-the-way.html



Technology

RATS SHOW ROBOTS THE WAY

A car fitted with a navigation system inspired by a rat's brain has successfully mapped a 66-kilometre road network in a suburb of Brisbane, Australia. Built by Michael Milford and Gordon Wyeth at the University of Queensland in St Lucia, the system is designed to give future autonomous robotic vehicles the ability to explore and map their environment.

At its heart is a neural network that mimics the way a rat makes a mental map of an area as it scurries through it – a concept known as simultaneous localisation and mapping. Specialised neurons in a rat's brain called "place", "head-direction" and "grid" tell the animal what direction it is facing and if the environment is a familiar one. Neural networks inspired by rat brains have previously been used to guide robots around simple lab mazes, but Milford and Wyeth's is the first to mimic the way grid neurons cope with an unfamiliar environment.

Running on a computer with a webcam feeding it video as the car drives around, the neural network maps an area by looking for landmarks such as junctions, trees and buildings, and recording the direction it is facing when it sees them. When it revisits an area and recognises a slightly altered view of a familiar landmark, it looks back over other landmarks it has recently passed to confirm its location, and updates its map accordingly. "It works out where the car is in the suburb even when the visual information it's getting is very ambiguous or confusing," says Milford.

A report on Milford and Wyeth's system will appear in *IEEE Transactions in Robotics* later this month.

Haven't I been here before?

June 2007, Radio: ABC Radio
http://www.abc.net.au/queensland/conversations/stories/s1943051.htm

Michael Milford toyed around with the idea of being a trumpet player before he graduated high school in 1998. He decided to become a rocket scientist instead, and studied Mechanical and Space Engineering at the University of Queensland. He also tutored high school students, and recognising they needed practical textbooks that spoke their language, he wrote his first educational textbook in Maths when he was 18. Now he's completed a PhD in Robotics and Artificial Intelligence - and he was a finalist for Young Queenslander of the Year.

Now Michael is part of a team studying animal behaviour to develop the perfect robot! "Just about every animal is under study at the moment," he says. "My specific area of relative expertise is rats. They're a nice blend of complexity and simplicity... They're fairly sophisticated, they can achieve fairly complex tasks, but we still know a fair amount about how their brain functions - much more than we know about the human brain."

There have been huge advances in robotics research. "One of the most impressive robots in the world at the moment is about one and a bit metres tall... It looks like a ten-year-old child; it can walk, it can run, it can open doors... That's the amazing pace that robotics research is advancing at the moment."

However, we don't have to worry about robots taking over from humans - yet! "So far the emotional robotics is very - I guess you'd say - fake... If that keeps advancing and we get to ones that can actually fool people, then we'll get into all sorts of issues of really trying to distinguish between a human and a robot, but I think that's a long way off."

Several dozen articles in international, national and regional newspapers and magazines including *The Australian Newspaper* and *Defence Technology International*. Several radio interviews.

Supervision of Students related to Thinking Systems

2009 onwards – Associate Supervisor, PhD Candidate William Maddern
2008 – Supervisor, Thesis Student Jeremy Norton
2007 – 2008 – Supervisor, Research Assistant William Maddern

Grants

2007: $11k. M. Milford, *Learning Optimal Foraging Behaviour in Real-World Environments*, University of Queensland New Staff Research Start Up Grant

Spiking Hippocampal Models for Learning and Recall of Places and Paths

Christopher Nolan

Summary

Navigation is a foundational skill for animals. From insects to birds to mammals, many animals have developed various strategies to search for that which they require, remember its location, then safely return home. Discovering some of the techniques these animals use has yielded unique solutions for the navigational problems of artificial autonomous systems. Yet many questions remain unanswered regarding the navigational abilities that so many animals appear to possess.

One such ability is path planning – learning a set of places in an environment and the connectivity between those places, then using the resulting graph or map for myriad goals. Empirical data collected over the past century indicates that some animals, and specifically rodents, are capable of behaviours difficult to reconcile using alternative explanations. In more recent decades, since the discovery of spatially sensitive ‘place cells’ in the rat brain, it has become clear that the hippocampus plays a significant role in map-based navigation. Simultaneously developing in the field of mobile autonomous systems have been algorithmic techniques to solve a similar map-based navigation problem, termed Simultaneous Localisation and Mapping (SLAM), which highlight the information-theoretical principles involved. The goal of the current work has been to explore, using spiking neural modelling techniques, how the electrophysiological and anatomical properties of the rodent hippocampus can satisfy these theoretical requirements of an online path planning system.

Recognition of novelty is a key element of any memory system. Existing studies have demonstrated both learning mechanisms capable of developing appropriate unique memories, and corresponding recall mechanisms capable of ignoring random variance in the input. These features are necessary for navigational memory from a theoretical perspective, and also provide a good fit for some electrophysiological data. However these studies have neglected to address the issue of when each process, learning and recall, should occur. As one element of the current work, we extended the existing models of the hippocampal network, incorporating the timing of individual spikes, and using this extra dimension to provide an internal novelty signal. More specifically, we implemented a network that matches known hippocampal anatomy, and demonstrated how such a network could instigate a race between a teaching signal and recall signal, with the teaching signal winning the race only in the case of a novel input (see Figure 1). Using this novelty signal, what constitutes a novel input can itself be modified dynamically, without destabilising the system.

Single temporal snapshots provide input which can be used to learn individual places, however paths are inherently non-instantaneous. Rather than individual memories, paths can be represented as sequences of places. Again, existing studies provide theories of how such sequences may arise, for example via temporal compression across different frequency brain rhythms. Using the varying spatial scales present in the spatial fields of cells across the hippocampus, and introducing further anatomical detail, we have developed an extended theoretical model that appears to explain and fit many electrophysiological observations. This theoretical model challenges one oft-made assumption regarding the nature of the information encoded by hippocampal spatially-sensitive cells. We suggest that while these cells have spatial fields, the location the cell is coding for is more specific than its spatial field, and that these cells also carry significant path information.

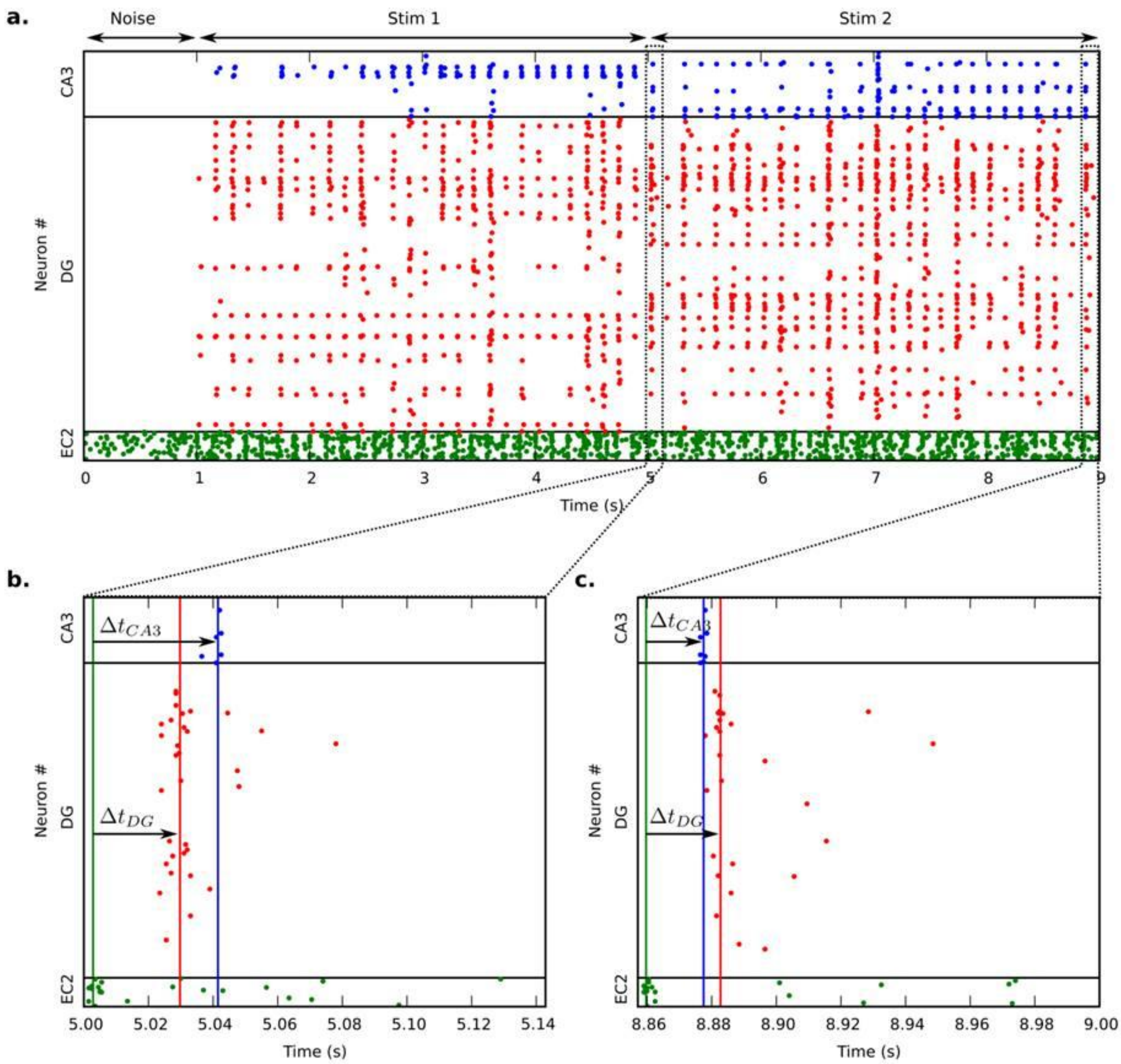


Figure 1. Response timing distinguishes learned from novel inputs: Initially the input (green dots) is novel, and although the input is directly connected to the output cells (blue dots), the output cells are slow to activate, not responding until the input activates the teaching signal (red dots) (highlighted for stimulus 2 in b). After repeated presentations, output cells start responding faster, activated directly by the recall signal and eventually respond before the arrival of the teaching signal (highlighted for stimulus 2 in c).

Publications

Nolan, C.R., Wyeth, G.F., Milford, M.J., Wiles, J. (2010) “The Race to Learn: Spike Timing and STDP Can Coordinate Learning and Recall in CA3”, *Hippocampus*. DOI: 10.1002/hipo.20777

Conference Abstracts

Nolan, C.R., Wyeth, G.F., Milford, M.J., Wiles, J. (2010) A neural microcircuit using spike timing for novelty detection. Computational and systems neuroscience 2010. doi: 10.3389/conf.fnins.2010.03.00099.

Continuous Appearance-based Localisation and Mapping

Will Maddern

The future capabilities of mobile robots depend strongly on their abilities to navigate and interact in the real world. A key requirement for navigation is an internal representation of the environment that the robot inhabits, along with the robot's location within the environment. Determining this using only information from onboard sensors is commonly referred to as Simultaneous Localisation and Mapping (SLAM). To avoid computational and scaling limitations, a number of SLAM approaches forsake geometric accuracy for flexibility to form semi-metric or non-metric 'topological' approaches. The two most successful non-geometric SLAM algorithms are RatSLAM and FAB-MAP. RatSLAM is based on a computational model of the rodent hippocampus, and is not a probabilistic system. FAB-MAP forsakes map building entirely and instead focuses on visual data association (so-called 'SLAM in appearance space').

My project aims to develop a novel SLAM solution grounded in probabilistic SLAM techniques, but incorporating characteristics of both RatSLAM and FAB-MAP to produce a highly capable, generally applicable solution for mobile robotics. The system will use vision as the primary sensory method, and generate a novel semi-metric trajectory-based map. Additionally, the system will require minimal tuning or calibration to work in a particular environment to provide greater ease of use; as with probabilistic SLAM systems the majority of parameters will be measurable properties of the robot platform. The key innovations of this system will be the use of continuous, non-geometric feature representation and trajectory-based pose filtering, both characteristics of RatSLAM, as well as principled visual data association in the style of FAB-MAP.

Published Work

Published work arose from both an initial study into a combination of FAB-MAP and RatSLAM. We performed two large-scale outdoor experiments with a hybrid RatSLAM-FAB-MAP system, demonstrating that it could successfully map a 66km route through an entire suburb as well as an 18km route repeated at many different times of day across a period of 3 weeks. This study served to illustrate many of the shortcomings of both algorithms; neither algorithm alone could complete the full day mapping, and many of the inaccuracies were due to the underlying feature detection rather than the probabilistic data association.

Current Work

I developed a new approach to probabilistic visual matching combined with vehicle odometry. This approach combines optical flow on a spherical plane with a bag-of-words matching algorithm to extrapolate the appearance of a visual scene from an initial location plus an arbitrary displacement. By performing this repeatedly over multiple displacements with multiple estimates of the average distance to features, the mean distance can be found using ML estimation. The study demonstrated that extrapolating feature appearance over a distance of 20m increased the matching performance by an average of 12dB over static image matching (as used by FAB-MAP). Figure 1 illustrates the feature extrapolation process. I am currently extending the feature extrapolation process to include interpolation between multiple images, with the goal of forming a continuous feature representation from a series of discrete snapshots of an environment with accompanying visual odometry.

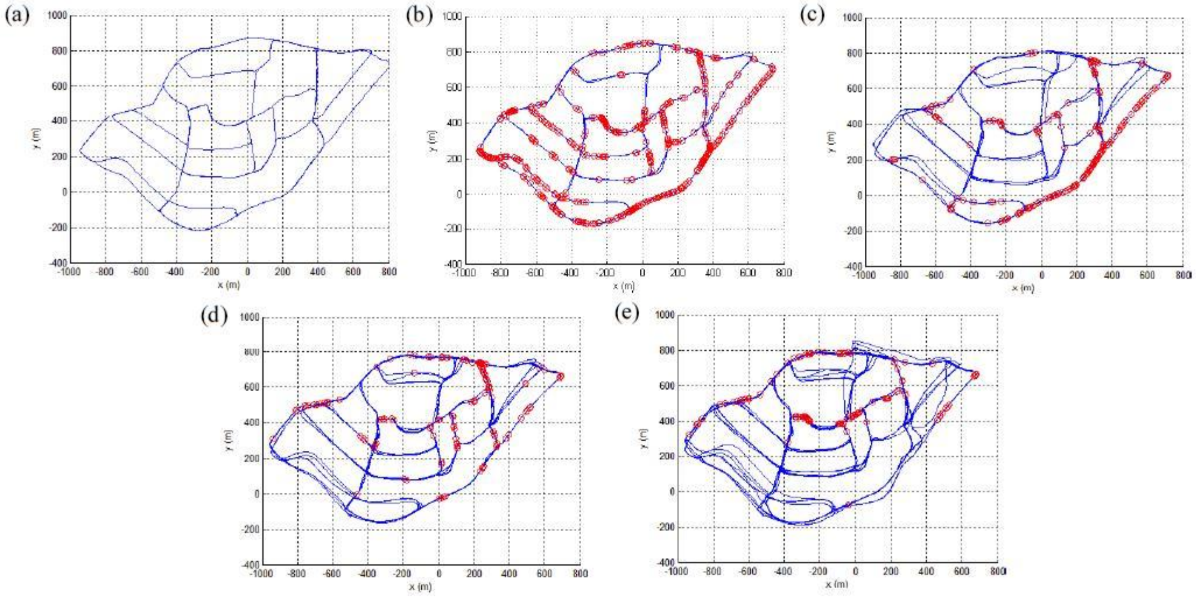


Figure 1. RatSLAM-created experience maps and loop closure locations using FAB-MAP data association. Sequentially including (a) 8:45am (b) 10:00am (c) 12:10pm (d) 2:10pm and (e) 3:45pm.

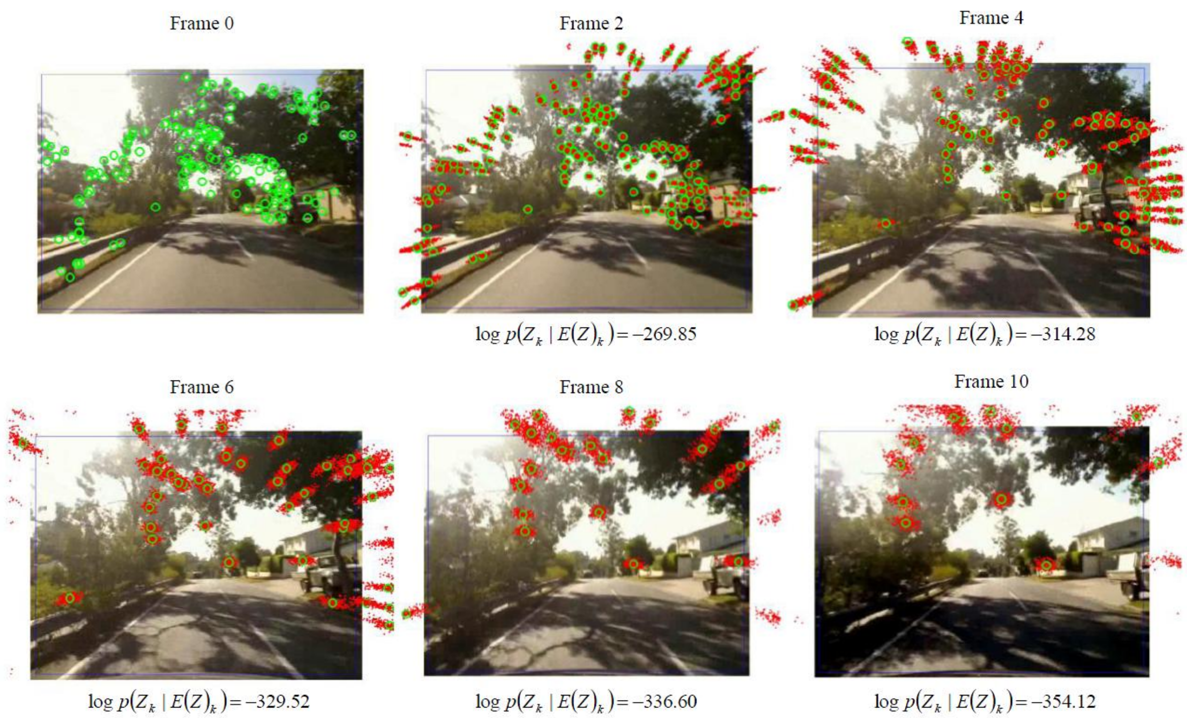


Figure 2. Predicted feature locations and uncertainty for a sample sequence of images. Feature locations are denoted by green circles and the Monte Carlo sampled locations for each feature are shown as red dots approximating the feature covariance.

I developed a new approach to probabilistic pose filtering along a trajectory using techniques from FastSLAM and FAB-MAP. The novel algorithm, dubbed Continuous Appearance-based Trajectory SLAM (CAT-SLAM), conditions the joint distribution of the observation and motion model on a continuous trajectory of previously visited locations. The distribution is evaluated using a Rao-Blackwellised particle filter, which represents location hypotheses as particles constrained to the trajectory. We compared the performance of CAT-SLAM to FAB-MAP (an appearance-only SLAM algorithm) in an outdoor environment, demonstrating a threefold increase in the number of correct loop closures detected by CAT-SLAM, illustrated in Figure 3. The results of the mapping experiment demonstrated that the combination of both appearance and motion information in CAT-SLAM provides a clear advantage over appearance-based SLAM systems that rely on visual data alone for applications that require 100% precision loop closure. The improvement over FAB-MAP is twofold; first, the addition of a pose filter allows spurious false positives to be rejected, and it allows a location hypothesis to be maintained with only partial visual matches.

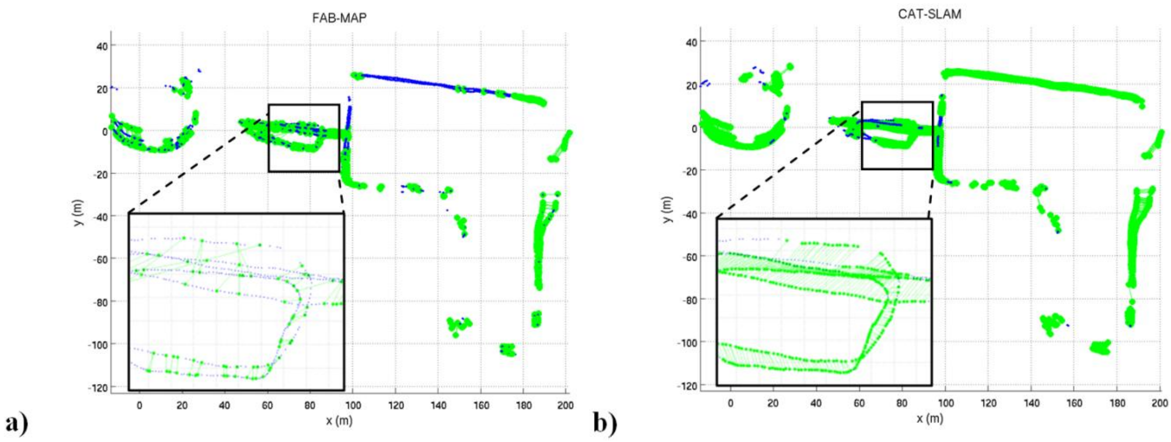


Figure 3. Loop closures projected on GPS ground truth for a) FAB-MAP and b) CAT-SLAM. Lighter green points indicate true positives and darker blue points false negatives. Insets illustrate sequential loop closure performance.

Conference Abstracts

Maddern, W. P., Glover, A.J., Milford, M.J., Wyeth, G.F. (2009) “Augmenting RatSLAM using FAB-MAP-based Visual Data Association”, in proceedings of the Australasian Conference on Robotics and Automation, Sydney, Australia.

Glover, A., Maddern, W., Milford, M.J., Wyeth, G.F. (2010) “FABMAP + RATSLAM: Appearance-based SLAM for Multiple Times of Day”, *IEEE International Conference on Robotics and Automation 2010*, Anchorage, Alaska.

Submissions

Maddern, W., Milford, M.J., Wyeth, G.F. (2010). "Loop Closure Detection on a Suburban Road Network using a Continuous Appearance-based Trajectory", submitted to the Australasian Conference on Robotics and Automation, Brisbane, Australia.

Maddern, W., Wyeth, G.F., (2010) "Egomotion Estimation with a Biologically-Inspired Hemispherical Camera", submitted to the Australasian Conference on Robotics and Automation, Brisbane, Australia.

Maddern, W., Milford, M.J., Wyeth, G.F. (2010). "Continuous Appearance-based Trajectory SLAM", submitted to the International Conference on Robotics and Automation, Shanghai, May 2011.

Maddern, W., Milford, M.J., Wyeth, G.F. (2010). "Predicting Feature Disappearance for Extrapolation of Observations in Appearance-based SLAM", submitted to the International Conference on Robotics and Automation, Shanghai, May 2011.

Related Activities

I attended the 8th ACEVS-CVS Summer School on Animal Navigation, held at the Queensland Brain Institute from 23-27 November 2009.

Theme 4: From physical to conceptual spaces

Humans are exquisite navigators, yet little is known about the environmental cues upon which we rely when finding our way in new or otherwise unfamiliar environments. Research in this theme has sought to determine the neural and cognitive processes responsible for object location-memory and landmark-based navigation in adult human participants. Across a series of experiments, the team has used functional magnetic resonance imaging to reveal the neural correlates of encoding and retrieval of visual landmarks in novel, virtual arenas. The research has also discovered, for the first time, a dedicated human brain region that encodes heading direction, a cue that is crucial in most way-finding situations. In further experiments, the team has demonstrated that the spatial disposition of contextual cues, such as those relating to the alignment of object locations relative to one another within a novel environment, exerts a unique influence on cognitive and neural representations of visual space. Finally, the team has examined the effects of cerebral stroke on a variety of navigation processes.

Project Members

Theme Leader	Jason Mattingley
Chief Investigators	Michael Arbib, John O'Keefe, Andrew Smith, Janet Wiles, Gordon Wyeth
Research Fellow	Oliver Baumann
PhD Student	Edgar Chan
Technology Support and Research Assistants	Jack Valmadre (2010), Daniel Clark (2009), Mark Wakabayashi (2007), Robert Ninnes and Ashley Skilleter
Collaborators	In Thinking Systems: Paul Stockwell
Honours Student	Amy Collins

Neural and Behavioral Correlates of Human Navigation

Oliver Baumann

My research concerns the cognitive processes and neural circuits that underlie our 'sense of direction' and the distinct processes of memory encoding and retrieval during active navigation through three-dimensional space. The research methods used include the assessment of behavioural performance as well as neuroimaging techniques.

In our initial experiment (Baumann, Chan & Mattingley, Neuroimage, February 1, 2010) we sought to identify the neural circuits that underlie the distinct processes of encoding and retrieval during landmark-based navigation. We used functional magnetic resonance imaging (fMRI) to measure neural responses as participants learned the location of a single target object relative to a small set of landmarks. Following a delay, the target was removed and participants were required to navigate back to its original position (Figure 1).

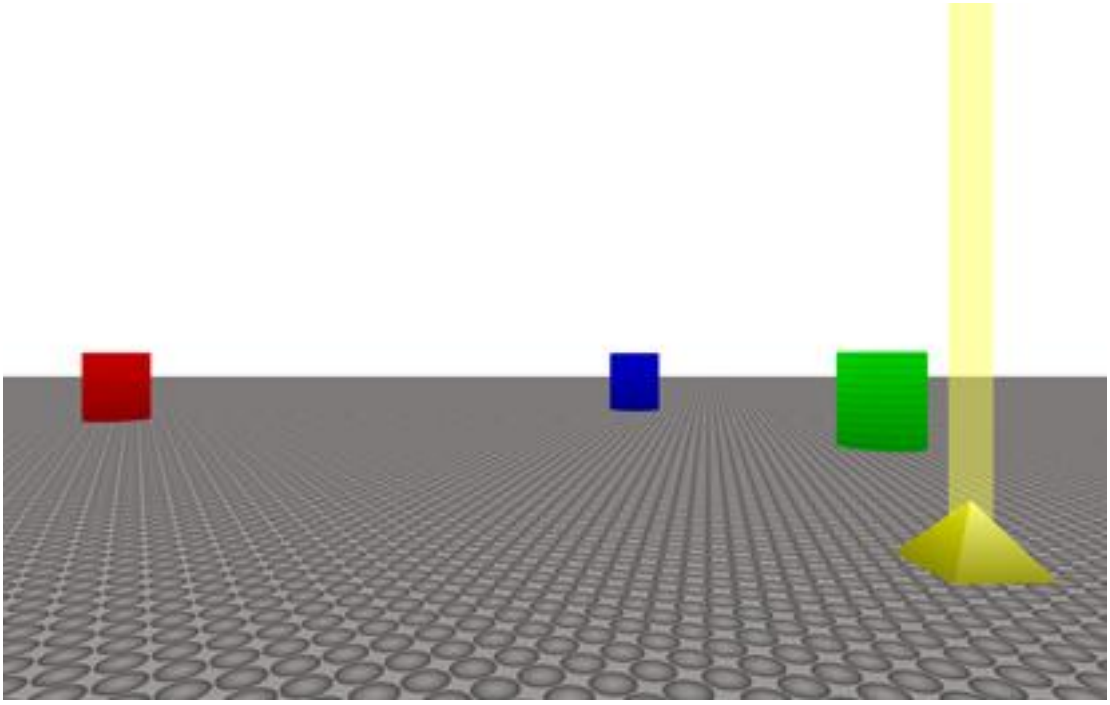


Figure 1: Schematic of the virtual environment used in the navigation task

At encoding, greater activity within the right hippocampus and the parahippocampal gyrus bilaterally predicted more accurate navigation to the hidden target object in the retrieval phase. By contrast, during the retrieval phase, more accurate performance was associated with increased activity in the left hippocampus and the striatum bilaterally. Dividing participants into good and poor navigators, based upon behavioural performance, revealed greater striatal activity in good navigators during retrieval, perhaps reflecting superior procedural learning in these individuals. By contrast, the poor navigators showed stronger left hippocampal activity, suggesting reliance on a less effective verbal or symbolic code by this group (Figure 2).

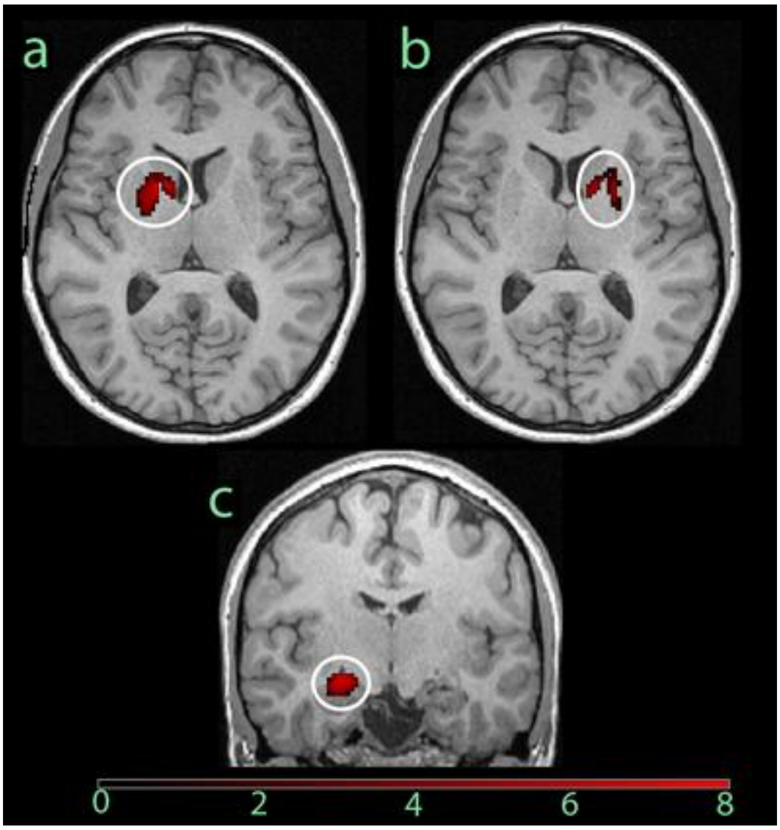


Figure 2: Magnetic resonance brain slices showing mean functional activity from the analysis comparing good and poor navigators during the retrieval phase. Good navigators showed stronger activity in two regions. (a) Left striatum. (b) Right striatum. Poor navigators showed stronger activity in a single region. (c) Left hippocampus.

Our findings suggest separate neural substrates for the encoding and retrieval stages of object location memory during active navigation, which are further modulated by participants' overall navigational ability.

Another cognitive function, crucial for successful navigation, is the ability to encode and update representations of heading direction. In rats, head-direction cells located within the limbic system alter their firing rate in accordance with the animal's current heading. However until now, the neural structures that underlie an allocentric or viewpoint-independent sense of direction in humans remained unknown. The goal of our second study (Baumann & Mattingley, The Journal of Neuroscience, September 29, 2010) was therefore to identify brain regions that are modulated by learned heading. We used functional magnetic resonance imaging to measure neural adaptation to distinctive landmarks associated with one of four heading directions in a virtual environment. Our experiment consisted of two phases: a "learning phase," in which participants actively navigated the virtual maze; and a "test phase," in which participants viewed pairs of images from the maze while undergoing fMRI (Figure 3).

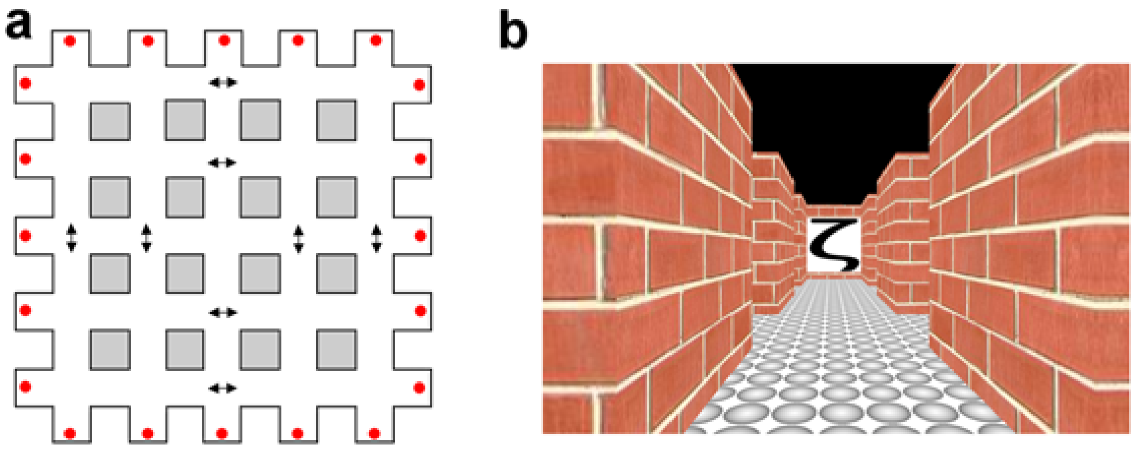


Figure 3: Schematics of the virtual environment used to examine the representation of allocentric heading. (a) Aerial perspective of the virtual maze used in the learning phase. The red dots indicate the locations of the 20 symbols that acted as landmarks; The arrows represent the 16 different vantage points from which participants viewed the landmarks during the test phase. (b) Example of a single image viewed by participants during the test phase.

We found that activity within the medial parietal cortex—specifically, Brodmann area 31—was modulated by learned heading, suggesting that this region contains neural populations involved in the encoding and retrieval of allocentric heading information in humans (Figure 4).

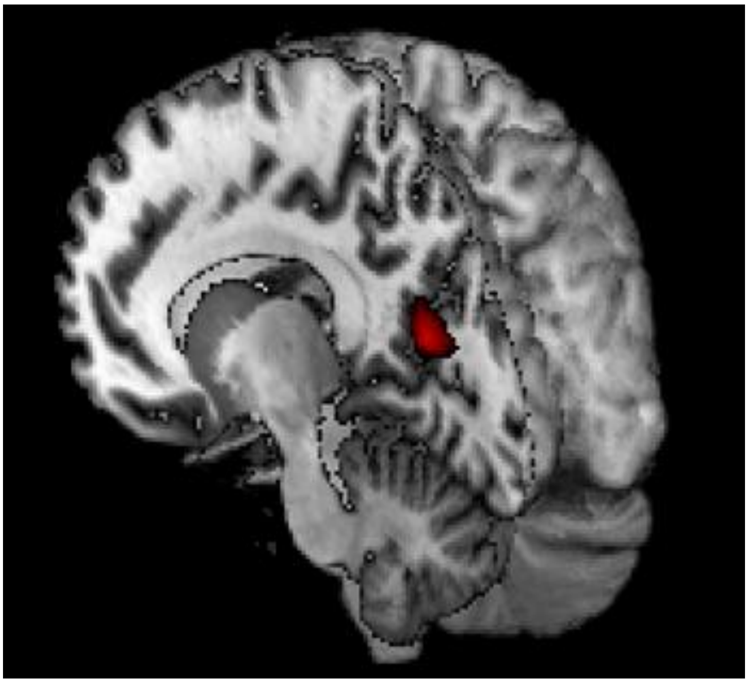


Figure 4: A magnetic resonance image of an MNI-normalized brain that shows heading-direction-selective activity in the left medial parietal cortex.

These results are consistent with clinical case reports of patients with acquired lesions of medial posterior brain regions, who exhibit deficits in forming and recalling links between landmarks and directional information. Our findings also help to explain why navigation disturbances are commonly observed in patients with Alzheimer's disease, whose pathology typically includes the cortical region we have identified as being crucial for maintaining representations of heading direction.

We are currently finalising a series of follow-up studies, with the aim to investigate further aspects of how humans use, process and memorise landmarks for spatial navigation. Our aim is to gain a comprehensive understanding of the fundamental properties of objects as landmarks, the cognitive processes involved in the identification and storage of these landmarks, and its ultimate effect on human navigation.

Ongoing Collaborative Research

GO8-DAAD Collaboration with Prof. Mark W. Greenlee at the University of Regensburg. Project Title: Visual-Vestibular Interactions for active navigation and spatial object-location memory.

Collaboration with Paul Stockwell and Andrew Smith: The study seeks to compare the algorithmic techniques for generating concept maps against those created by humans.

Publications (2008-2010):

Baumann, O., Mattingley, J.B. (2010b) Medial parietal cortex encodes perceived heading direction in humans. *Journal of Neuroscience* 30: 12897-12901.

Baumann, O., Mattingley, J.B. (2010a) Scaling of neural responses to visual and auditory motion in the human cerebellum. *Journal of Neuroscience* 30: 4489-4495.

Baumann, O., Chan, E., Mattingley, J.B. (2010) Dissociable neural circuits for encoding and retrieval of object locations during active navigation in humans. *NeuroImage* 49:2816-2825.

Magnussen, S., Greenlee, M.W., Baumann, O., Endestad, T. (2010) Visual perceptual memory - anno 2008. In: *Memory, aging and the brain*. Bäckman L, Nyberg L, eds. London: Psychology Press.

Baumann, O., Belin, P. (2010) Perceptual scaling of voice identity: common dimensions for different vowels and speakers. *Psychological Research* 74: 110-120.

Baumann, O., Greenlee, M.W. (2009) Effects of attention to auditory motion on cortical activations during smooth pursuit eye tracking. *PLoS ONE* 4:9

Baumann, O., Endestad, T., Magnussen, S., Greenlee, M.W. (2008) Delayed discrimination of spatial frequency for gratings of different orientation: behavioral and fMRI evidence for low-level perceptual memory stores in early visual vortex. *Experimental Brain Research* 188:363-369.

Submissions

Baumann O., Skilleter, A., Mattingley J.B. Short-term Memory Maintenance of Object Locations during Active Navigation: Which Working Memory Subsystem is Essential?

Chan E., Baumann, O., Bellgrove, M., Mattingley, J.B. (2010) The influence of environmental cues on the formation of object-location representations within a virtual environment.

Conference Abstracts

Baumann, O., Mattingley J.B. (2010) Retrosplenial cortex encodes heading direction in humans. Human Brain Mapping Meeting, Barcelona, Spain, June.

Baumann, O., Mattingley, J.B. (2010) Scaling of neural responses to visual and auditory motion in the human cerebellum. Human Brain Mapping Meeting, Barcelona, Spain, June.

Baumann, O., Mattingley, J.B. (2010) Retrosplenial cortex encodes heading direction in humans. 37th Australasian Experimental Psychology Conference, Melbourne, April.

Chan, E., Baumann, O., Bellgrove, M., Mattingley, J.B. (2010) The influence of environmental cues on the formation of object-location representations within a virtual environment. 37th Australasian Experimental Psychology Conference, Melbourne, April.

Baumann, O., Chan, E., Mattingley, J.B. (2009) Hippocampal, parahippocampal and striatal neuronal activity predicts object-location retrieval during active navigation. 9th Conference of the Australasian Society for Cognitive Science, Sydney, September.

Chan, E., Baumann, O., Bellgrove, M., Mattingley, J.B. (2010) The influence of environmental cues on the formation of object-location representations within a virtual environment. 9th Conference of the Australasian Society for Cognitive Science, Sydney, September.

Baumann, O., Chan, E., Mattingley, J.B. (2009) Hippocampal, parahippocampal and striatal activity predicts object-location recall during active navigation. Cognitive Neuroscience Society Annual Meeting, San Francisco, USA, March.

Baumann, O., Endestad, T., Magnussen, S., Greenlee, M.W. (2008) Perceptual memory representations studied in delayed discrimination of spatial frequency - behavioral and fMRI evidence for high-fidelity visual stores in early visual cortex. Human Brain Mapping Meeting, Melbourne, June.

Baumann, O., Endestad, T., Magnussen, S., Greenlee, M.W. (2008) Delayed discrimination of spatial frequency for gratings of different orientation: behavioral and fMRI evidence for low-level perceptual memory stores in early visual. Cognitive Neuroscience Society Annual Meeting, San Francisco, USA, April.

Related Activities

Guest lecture on human spatial navigation in the Cognitive Neuroscience course at the School of Psychology, University of Queensland, Brisbane (2010)

Invited speaker at the QBI Neuroscience Seminar, Brisbane (2010)

Attendee at the Brain Products Workshop and Training Course, Brisbane (2010)

Poster presentation at the Human Brain Mapping Meeting, Barcelona, Spain (2010)

Oral presentation at the 37th Australasian Experimental Psychology Conference, Melbourne (2010)

Invited speaker at the Summer School on Animal Navigation, Brisbane (2009)

Guest lecture on human spatial navigation in the Cognitive Neuroscience course at the School of Psychology, University of Queensland, Brisbane (2009)

Oral presentation at the 9th Conference of the Australasian Society for Cognitive Science, Sydney (2009)

Poster presentation at the Cognitive Neuroscience Society Annual Meeting, San Francisco, USA (2009)

Attendee at the FSL & Freesurfer course, Brisbane (2009)

Guest lecture on human spatial navigation in the Cognitive Neuroscience course at the School of Psychology, University of Queensland, Brisbane (2008)

Poster presentation at the Human Brain Mapping Meeting, Melbourne (2008)

Poster presentation at the Cognitive Neuroscience Society Annual Meeting, San Francisco, USA (2008)

Attendee at the Summer School on Animal Navigation, ANU, Canberra (2007)

Supervision of undergraduate, summer or honours students related to Thinking Systems

Supervision of an Honour's thesis at the School of Psychology, University of Queensland: Working Memory in Spatial Navigation: Which Subsystem is Essential for Object Location Memory? Amy Collins, BSc (2009)

Grants

Baumann, O., Mattingley, J.B. UQ New Staff Start-up Grant: Topographic and temporal analysis of cerebellar neural activity related to attentional, perceptual and memory processes (2008).

Mattingley, J.B., Greenlee, M.W., Baumann, O.B. Go8 Germany Joint Research Co-operation Grant: Visual-Vestibular Interactions for active navigation and spatial object-location memory (2010-2011).

Media Coverage

O. Baumann. Australian Geographic: “Sense of direction can be learned” (08.10.2010)
http://www.australiangeographic.com.au/journal/sense-of-direction-can-be-learned.htm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Sense of direction can be learned

BY: EMMA YOUNG | OCTOBER-8-2010

TAGS: biology, news, people, science, science & environment

Humans aren't so good at finding their way around, but sense of direction can be improved with training.

BLINDFOLD A GOLDEN HAMSTER and take it on a meandering route away from its nest then let it go, and it can scurry straight home. Other animals, like geese and toads, and especially pigeons, are experts when it comes to sensing direction. People don't perform so well. However, new work by Australian scientists shows that part of our brain is in fact dedicated to detecting the direction we're heading in.

"Our study provides not only the first evidence for a brain region sensitive to heading direction in people, but also its precise location in the brain," says Oliver Baumann of the Queensland Brain Institue, who led the work.

Oliver and colleague Jason Mattingley asked six women and seven men to navigate their way around a computer-generated maze. This maze consisted of a grid of alleys with a different symbol at the end of each one, which the volunteers learned to use as landmarks.

Humans can improve their skills at finding locations, new researcher suggests. (Photo: Getty)

O. Baumann. Queensland Brain Institute scientists find the brain's inner compass. Courier Mail.
http://www.couriermail.com.au/news/queensland/queensland-brain-institute-scientists-find-the-brains-inner-compass/story-e6freoof-1225931978553


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Last updated: September 30, 2010

Queensland Brain Institute scientists find the brain's inner compass

by Janelle Miles | The Courier-Mail | September 29, 2010 8:45PM | 1 comment

Oliver Baumann, Christopher Hogarty and 12 others recommend this. Undo

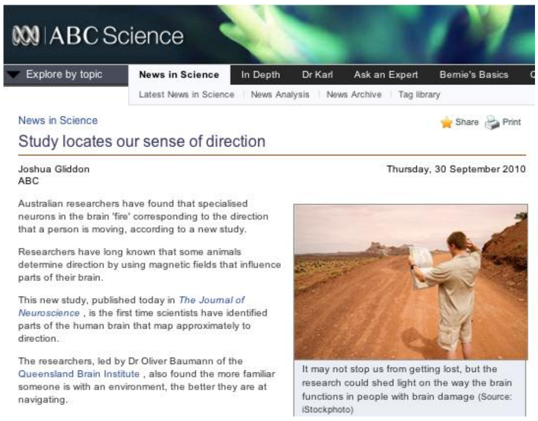
BRISBANE researchers have found the brain's "inner compass", a tiny area of cells responsible for a person's sense of direction.

The study by Queensland Brain Institute scientists explains why stroke and Alzheimer's patients who have damage in the region of the brain which contains the inner compass can easily become disoriented.

Further studies may also be able to test whether men really do have a better sense of direction than women.

Neuroscientist Oliver Baumann, based at the University of Queensland, said the inner compass – a sphere-shaped area about half a centimetre in diameter – was at the back of the brain in a region known as the parietal cortex.

O. Baumann. ABC Online: “Study locates our sense of direction” (30.09.2010)
http://www.abc.net.au/science/articles/2010/09/30/3025268.htm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News in Science

Study locates our sense of direction

Joshua Gliddon
ABC

Thursday, 30 September 2010

Australian researchers have found that specialised neurons in the brain 'fire' corresponding to the direction that a person is moving, according to a new study.

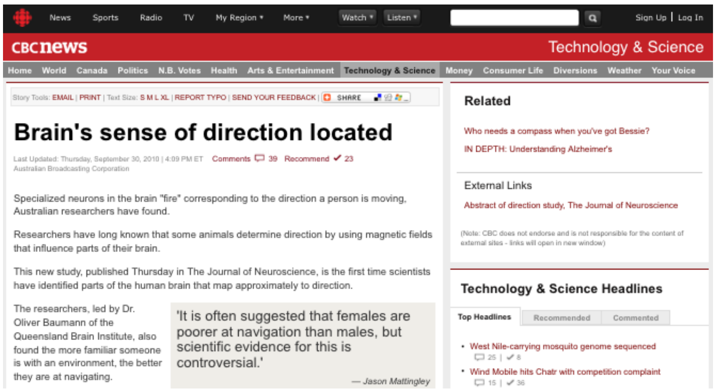
Researchers have long known that some animals determine direction by using magnetic fields that influence parts of their brain.

This new study, published today in *The Journal of Neuroscience*, is the first time scientists have identified parts of the human brain that map approximately to direction.

The researchers, led by Dr Oliver Baumann of the Queensland Brain Institute, also found the more familiar someone is with an environment, the better they are at navigating.

It may not stop us from getting lost, but the research could shed light on the way the brain functions in people with brain damage (Source: iStockphoto)

O. Baumann. CBC Online: “Brain’s sense of direction located” (30.09.2010)
http://www.cbc.ca/technology/story/2010/09/30/direction-brain.html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Brain's sense of direction located

Last Updated: Thursday, September 30, 2010 | 4:09 PM ET Comments 39 Recommend 23
Australian Broadcasting Corporation

Specialized neurons in the brain "fire" corresponding to the direction a person is moving, Australian researchers have found.

Researchers have long known that some animals determine direction by using magnetic fields that influence parts of their brain.

This new study, published Thursday in The Journal of Neuroscience, is the first time scientists have identified parts of the human brain that map approximately to direction.

The researchers, led by Dr. Oliver Baumann of the Queensland Brain Institute, also found the more familiar someone is with an environment, the better they are at navigating.

'It is often suggested that females are poorer at navigation than males, but scientific evidence for this is controversial.'
— Jason Mattingley

Related
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External Links
Abstract of direction study, The Journal of Neuroscience
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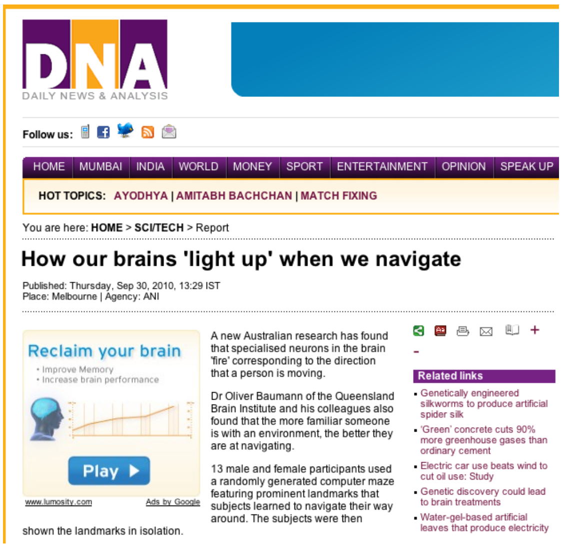
O. Baumann. Daily News and Analysis: “How our brains ‘light up’ when we navigate” (30.09.2010)
http://www.dnaindia.com/scitech/report_how-our-brains-light-up-when-we-navigate_1445632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How our brains 'light up' when we navigate

Published: Thursday, Sep 30, 2010, 13:29 IST
Place: Melbourne | Agency: ANI

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A new Australian research has found that specialised neurons in the brain 'fire' corresponding to the direction that a person is moving.

Dr Oliver Baumann of the Queensland Brain Institute and his colleagues also found that the more familiar someone is with an environment, the better they are at navigating.

13 male and female participants used a randomly generated computer maze featuring prominent landmarks that subjects learned to navigate their way around. The subjects were then shown the landmarks in isolation.

Related links
- Genetically engineered silkworms to produce artificial spider silk
- 'Green' concrete cuts 90% more greenhouse gases than ordinary cement
- Electric car use beats wind to cut oil use: Study
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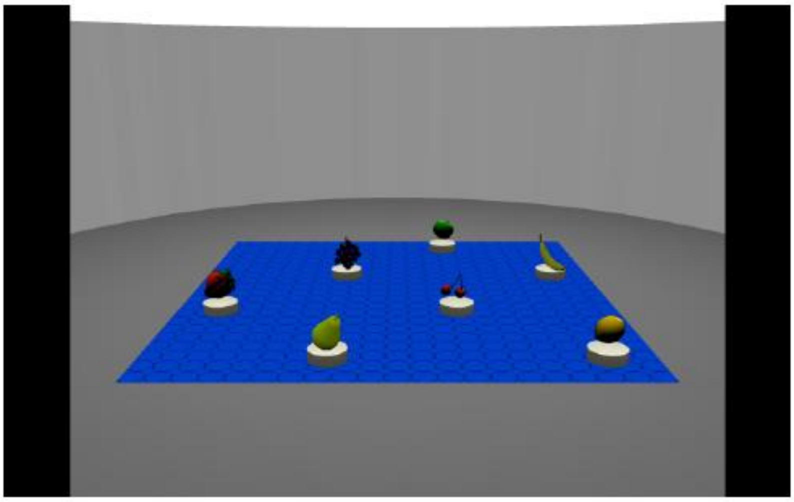
O. Baumann. Courier Mail: “Magnetic personality or not, we all have an inner campus” (30.09.2010)
O. Baumann. Sydney Morning Herald: “Mapping the brain” (30.09.2010)
O. Baumann. 702 ABC Sydney Radio Interview (30.09.2010)
O. Baumann. 91.7 ABC Coast FM Radio Interview (30.09.2010)
O. Baumann. Sydney Morning Herald: “Mapping the brain” (30.09.2010)

The Influence of Alignment on Object-Location Memory within a Virtual Environment

Edgar Chan

An enduring question in research on human navigation is whether memory for object locations in the environment is viewpoint-dependent or viewpoint-independent. One line of research has shown evidence to suggest that cues from the external environment (e.g., room geometry) can play a significant role in how an array of objects is encoded and retrieved. Specifically, retrieval of object-location information tends to be faster and more accurate when the retrieved orientation of the array is aligned with an axis defined by the external cue than when it is misaligned with this axis, even for orientations that were not presented during encoding. My research this year has focused on investigating the role of alignment cues on object-location memory within a novel virtual environment. Typically in my experiments, participants are shown an image of a circular arena containing seven distinct target objects, and are required to learn the locations of the objects to a criterion level of performance. A uniquely coloured square mat placed on the floor of the arena provides the cue to the intrinsic axis of the object array. To test their spatial knowledge of the array, participants are instructed to imagine themselves standing at a particular object location facing another object, and to point to the location of a third object. So far, we have found that participants responded faster and more accurately when the imagined heading was aligned as opposed to misaligned with the axis defined by the mat. We also found that the alignment effect is an enduring property of object-location memory, as it remains evident after a 24 hour delay; and that it can occur in the absence of any external visual cues. The alignment effect remains evident irrespective of whether the encoding of the object locations is achieved through static displays or a process of active navigation. Further studies are being conducted to investigate the influence of visual cueing during retrieval and to explore the neural correlates of the spatial alignment effect using fMRI.



Above: Example of the object-array shown to participants during the experiment.

Publications (2008-2010):

Baumann O., Chan E., Mattingley J.B. (2010) Dissociable neural circuits for encoding and retrieval of object locations during active navigation in humans. *NeuroImage* 49:2816-2825

Submissions

Chan, E., Baumann, O., Bellgrove, M., Mattingley, J.B. (2010) The influence of environmental cues on the formation of object-location representations within a virtual environment.

Conference Abstracts

Chan, E., Baumann, O., Bellgrove, M., Mattingley, J.B. (2010) The influence of environmental cues on the formation of object-location representations within a virtual environment. 37th Australasian Experimental Psychology Conference, Melbourne, April.

Chan, E., Baumann, O., Bellgrove, M., Mattingley, J.B. (2010) The influence of environmental cues on the formation of object-location representations within a virtual environment. 9th Conference of the Australasian Society for Cognitive Science, Sydney, September.

Baumann, O., Chan, E., Mattingley, J.B. (2009) Hippocampal, parahippocampal and striatal neuronal activity predicts object-location retrieval during active navigation. 9th Conference of the Australasian Society for Cognitive Science, Sydney, September.

Baumann, O., Chan, E., Mattingley, J.B. (2009) Hippocampal, parahippocampal and striatal activity predicts object-location recall during active navigation. Cognitive Neuroscience Society Annual Meeting, San Francisco, USA, March.

Related Activities

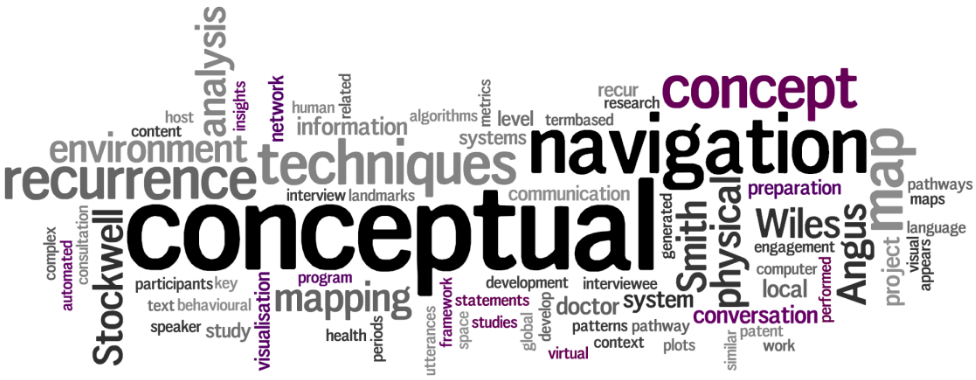
6th ACEVS-CVS Summer School on Animal Navigation (ANU) – 26th to 30th November 2007

Hippocampus and Navigation Workshop (Instituto Gulbenkian de Ciencia, Portugal) – 31st Mar to 4th April 2008

8th International FSL and FreeSurfer Course (UQ)– 23rd to 27th June 2008

Cognitive Neuroscience Lab Retreat (Stradebroke Island) – 1st to 3rd November 2008

HCSNet Workshop on SPM for FMRI – 18th to 20th November 2009



Theme 5: Navigating Information Spaces - Automated Conceptual Mapping Systems

This theme is using insights from biological navigation systems to develop algorithms for automated concept mapping. In particular, the aim is to understand how trajectories through information spaces are used to build maps and how to use maps to achieve goals.

Project Members

Theme Leader	Andrew Smith
Chief Investigators	Jason Mattingley, Janet Wiles, Jeff Elman
Research Fellow	Daniel Angus
PhD Students	Paul Stockwell
Software Engineer	Kris Rogers (2010)
Collaborators	In Thinking Systems: Allen Cheung, Oliver Baumann In Psychology: Cindy Gallois, Bernadette Watson In ITEE: Wei Luo
Commercial Partner	Leximancer Pty Ltd
Research Experience Students	Andrew Jones (2008-09)
Thesis Students	Hazem Alhakami (2010), Andrew Jones (2009) Michael Wildermoth (2009)

Concept Mapping Inspired by Physical Navigation

Daniel Angus

Theme 5 draws inspiration from principles of physical navigation. Insights generated by Theme 3 and 4, including how humans use landmarks to assist in executing physical navigation tasks, and the RatSLAM algorithm which is inspired by rodent hippocampal models, make for ideal starting points for investigation into concept navigation.

Theme 5 has been most interested in the development of conceptual mapping techniques which integrate spatial and temporal information. The focus of these techniques has been in trying to understand structure within conversation transcripts, particularly those that relate to speaker specific behaviours and characteristics. An important outcome from this work has been the creation of a conceptual recurrence visualisation system. The conceptual recurrence visualisation system is useful for analysis of transcribed spoken dialogue, and other input texts. The use of this technique in the determination of conversation participant behavioural metrics is the subject of an Australian Provisional Patent, and several papers are currently under review and in preparation.

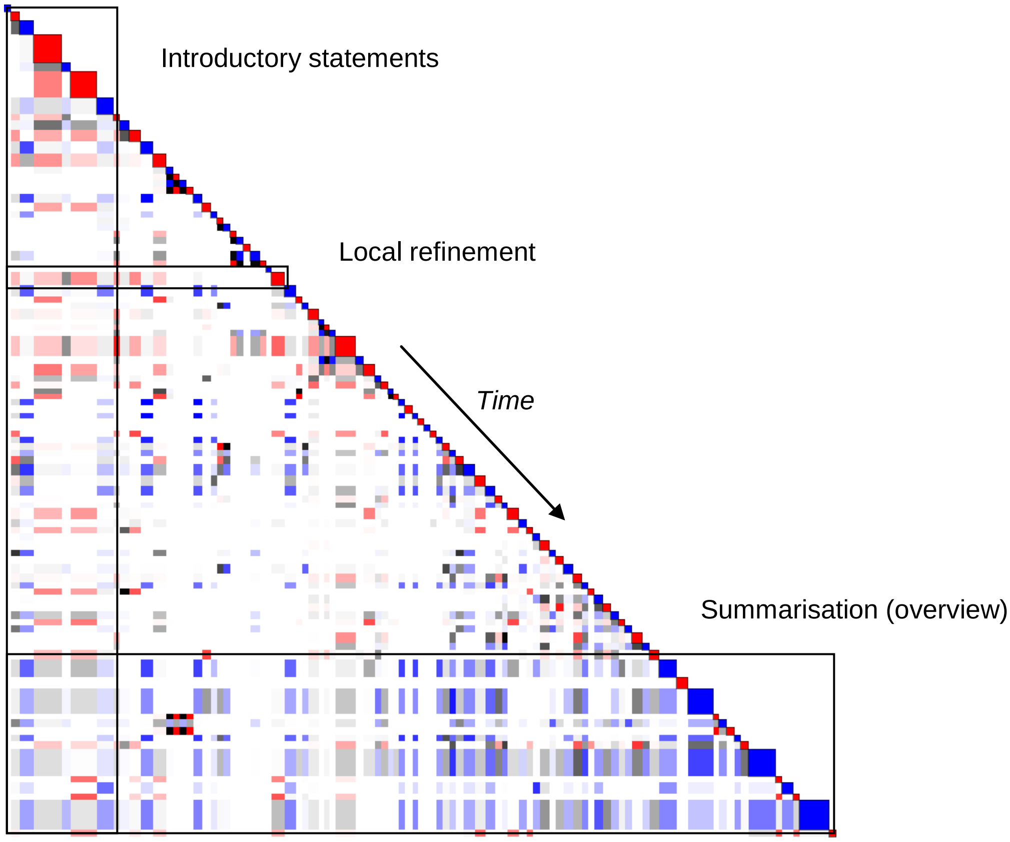


Figure 1: Global and local map building in a conceptual space. This conceptual recurrence plot is built using a transcript of a doctor/patient consultation. Each square on the diagonal refers to a turn in the consultation with the size representing the utterance length. The patient (in red) starts the conversation by outlining various symptoms and this step can be considered as the patient providing the global map. This map is then traversed by the doctor (in blue) and the patient by filling in local details as they go (local refinement). These local refinements recur with the statements made at the beginning of the consultation as well as other statements which refer to the same local detail. At the conclusion of the consultation the doctor offers an overview of the discussion which once again returns discussion to the level of the global map.

Text-based recurrence systems have been used previously to study early-language development by children among other applications, however these systems model language at a simple text (or term-based) level, rather than modelling it at a conceptual level. By working at a conceptual level our system can model conceptual recurrence which captures implied context within a single text. In the example provided we contrast a section of an interview from the SBS Insight program "Emergency" where a mother is discussing her son's burst appendix. In many of the utterances displayed the term appendix doesn't appear and as such the host, Jenny Brockie, appears to not recur with the interviewee when asking the question "And the appendix had bust?". When conceptual information is used, this statement appears to recur strongly as in reality the entire excerpt is related to this boy's burst appendix.

a) Term-based Recurrence b) Conceptual Recurrence

Figure 2: Contrasting term-based (term matched) recurrence plotting versus conceptual (context aware) recurrence plotting. In this excerpt from the SBS Insight program "Emergency" a mother (Susan Candlish) is discussing her son's burst appendix with the program host (Jenny Brockie). The addition of conceptual information allows statements that are conceptually similar to recur. This extra recurrence enables greater accuracy when calculating the degree of engagement between participants, among other behavioural metrics.

The conceptual recurrence visualisation system is currently being used for analysis of a variety of datasets from research and industry areas. Example applications include:

- Doctor/Patient consultations: Conceptual recurrence has been used as a precursor for the development of several participant behavioural metrics. These metrics correlate with good and poor communication patterns and we have been working in collaboration with colleagues in the School of Psychology to develop protocols for assisting with the assessment of Doctor/Patient communication.

- Childhood language development: Conceptual recurrence plots are useful in distinguishing language learning difficulties both on a qualitative and quantitative level. This work has been performed in conjunction with colleagues in the Temporal Dynamics of Learning Center in San Diego.

- Cockpit communication analysis: Analysis of flight-deck transcripts using conceptual recurrence plots show how leadership roles and listening roles are shared by airline staff.

- Television interviews: Conceptual recurrence plots are able to highlight complex interviewer/interviewee dynamics in a televised interview. Identification of topic engagement and repetition of key concepts can be used to highlight particular interview techniques being employed by an interviewee or interviewer.

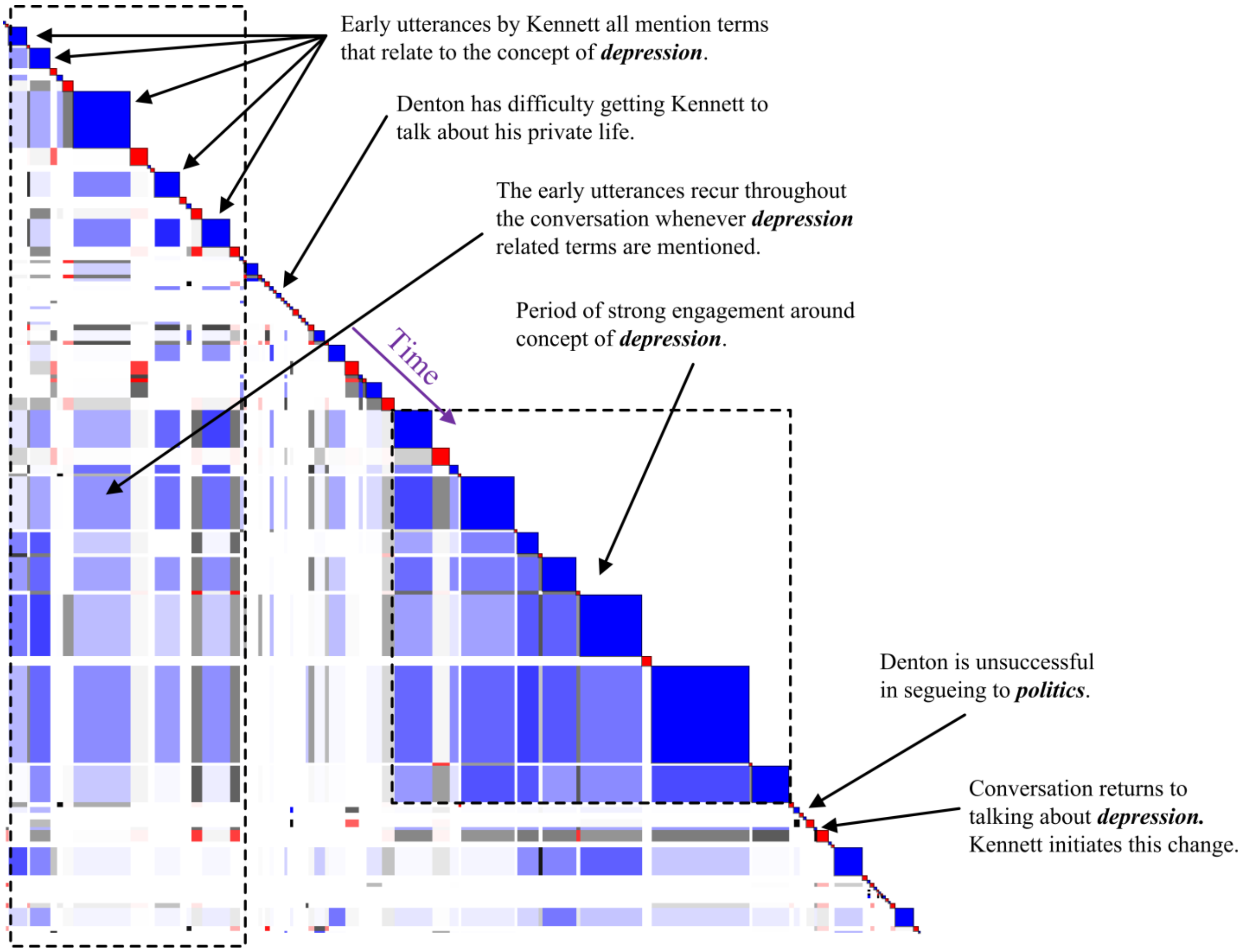


Figure 3: Conceptual recurrence plot for a conversation between Andrew Denton and Jeff Kennett on the ABC Enough Rope television program. Kennett is indicated in blue and Denton is indicated in red. Conceptual comparisons between both Kennett and Denton are coloured grey. Dark colour indicates conceptually similar utterances, while white space indicates dissimilar utterances. Using this visualisation we can identify periods of engagement between participants and interact with the system to determine what content they are talking about in these periods. We can also see how particular concepts recur throughout an interview, as in this particular example "depression" appears to be an important concept that is mentioned multiple times.

We have also been collaborating with members of Theme 2 and 3 to study how conceptual mapping techniques can be used to inform about qualities of physical and virtual environments. This work is bridging multiple themes by exploring questions about the role of spatial and episodic memory in physical and conceptual navigation systems. Conceptual mapping algorithms can generate models that can capture qualities about an environment including how landmarks may affect the navigability of the environment.

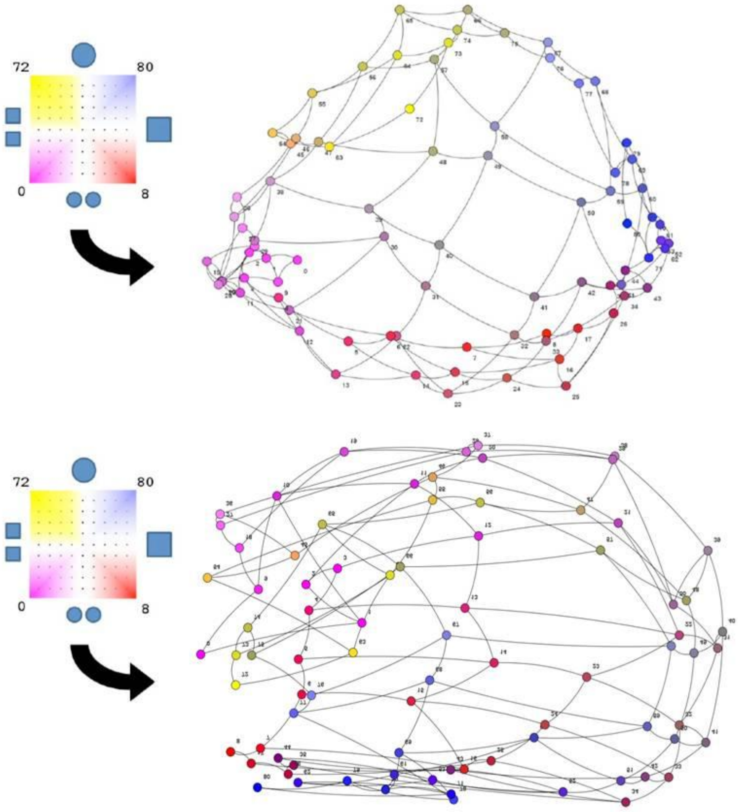


Figure 4: A virtual environment that has different landmarks at its four edges is sampled in a 9 x 9 grid pattern (left). The sampling takes panoramic images from each location and these images are placed according to their image similarity using a conceptual mapping algorithm (right). The nodes in the concept map each correspond to a physical location and each node is connected to its nearest neighbour in a Manhattan grid fashion. The shape of the conceptual map changes depending on the arrangement of objects in the environment and their appearance. The topmost map is generated from an environment that does not have any wall, whereas the bottom map is generated from an environment that includes a wall. In the topmost example the conceptual map implies that the corners appear as distinct places within the environment, in the bottommost example the corners have a higher visual similarity due to them being placed in a similar part of the conceptual map.

Ongoing Collaborative Research

Measuring complexity of real and virtual environments using conceptual mapping algorithms. Collaborator: Allen Cheung (Theme 2). This work bridges theme 2 and 5 by using conceptual mapping technologies to provide insight into the complexity of virtual environments that are used in virtual and real-world animal behaviour experimentation.

Publications

Angus, D., Woodward, C. (2009) Multiple Objective Ant Colony Optimisation. *Swarm Intelligence*, 3, 69-85

Angus, D. (2009) Niching for Ant Colony Optimisation. Biologically-Inspired Optimisation Methods: Parallel Algorithms, Systems and Applications. Lewis, A.; Mostaghim, S. & Randall, M. (ed.). Springer.

Angus, D., Deller, A. (2008) Computational Intelligence in Radio Astronomy: Using Computational Intelligence Techniques to Tune Geodesy Models. Simulated Evolution and Learning, 7th International Conference, SEAL08, Springer-Verlag, LNCS 5361, 615-624.

Angus, D. (2008) Niching Ant Colony Optimisation. PhD Thesis, Swinburne University of Technology.

Papers under Review

Angus, D., Smith, A. E., Wiles, J. “Conceptual Recurrence Plots: Revealing Patterns in Human Communication”, (under review by IEEE Transactions on Visualization and Computer Graphics).

Papers in Preparation

Angus, D., Cheung, A. “Measuring complexity of real and virtual environments using conceptual mapping algorithms”.

Angus, D., Smith, A. E., Wiles, J. “Measuring the Dynamics of Human Discourse”.

Angus, D., Smith, A. E., Watson, B., Gallois, C., Wiles, J. “Visualising the Structure of Conversation Behaviour: Insights into Doctor-Patient Consultations”.

Conference Abstracts or Poster

Angus, D. (2008) Biologically Inspired Concept Navigation, poster presentation at the Brain Plasticity Symposium, QBI, September 2008.

Patents

Australian Provisional Patent Application 2010903163 “A communications analysis system and process”, Angus, D., Smith, A. E., Wiles, J. Filing date: 15 July 2010.

Related Activities

Invited Speaker at Health Quality and Complaints Commission Network Research Session, Brisbane, Australia. Talk title: Health Data Visualization and Data Mining. Speakers: Wiles, J., Angus, D.

Attended the HCSNet Summerfest 2008 at the University of New South Wales. Organised and run by the ARC Human Communication Science Network.

Seminars, Tutorials, Courses Presented

Presented a tutorial at the 2009 Animal Navigation Summer School held at the Queensland Brain Institute. Tutorial title: Concept Navigation.

Lecturer for ENGG7302: Advanced Computational Techniques in Engineering in 2009 and 2010.

Supervision of Students related to Thinking Systems

Andrew Jones, Large Text Corpus Project, 2009.

Hazem Alhakami, Investigating the Limitations of Text Similarity Algorithms With Respect to the Amount of Input Text, 2010.

Navigating Concept Space as a Network: Making Connections between Concepts

Paul Stockwell

The amount of literature available to be read has been increasing dramatically In recent decades. For large or complex domains, automated tools can extract the key concepts from a body of text and represent the relationships between them in a two dimensional layout. Concept maps are a common method for visualising a domain.

This project uses the physical analogy of navigation in the context of conceptual space. The overall goal of this project is to investigate using pathways to look for probable or causal relationships between concepts or entities that are not directly related. The specific aims are to develop and test a mechanism for decomposing and representing a pathway in a textual domain as a “knowledge pathway”, which can then be used to aid in learning new concepts from a known starting point, or to determine if there is a credible link between two concepts or entities.

The method used in this project starts with extracting the key concepts from a textual corpus using content analysis, and then generating a concept map from it using Leximancer. Network graph techniques such as shortest paths create pathways within a concept map to link concepts that are not directly connected, while minimum spanning trees provide a visual framework that may assist in comprehending complex concept maps.

A series of studies have been completed during the project. The earlier studies looked at algorithmic techniques to provide visual cues and pathways. Next, more evaluative studies were performed, where the “irreducible complexity” of a corpus was investigated where the dimensional reduction of the document no longer accurately captures the underlying “story” of the original text. The current study seeks to compare the algorithmic techniques for generating concept maps against those created by humans. A small pilot study has been performed with the full study currently in final preparation.

This project has produced two publications, a patent, and has been partially commercialised by Leximancer.

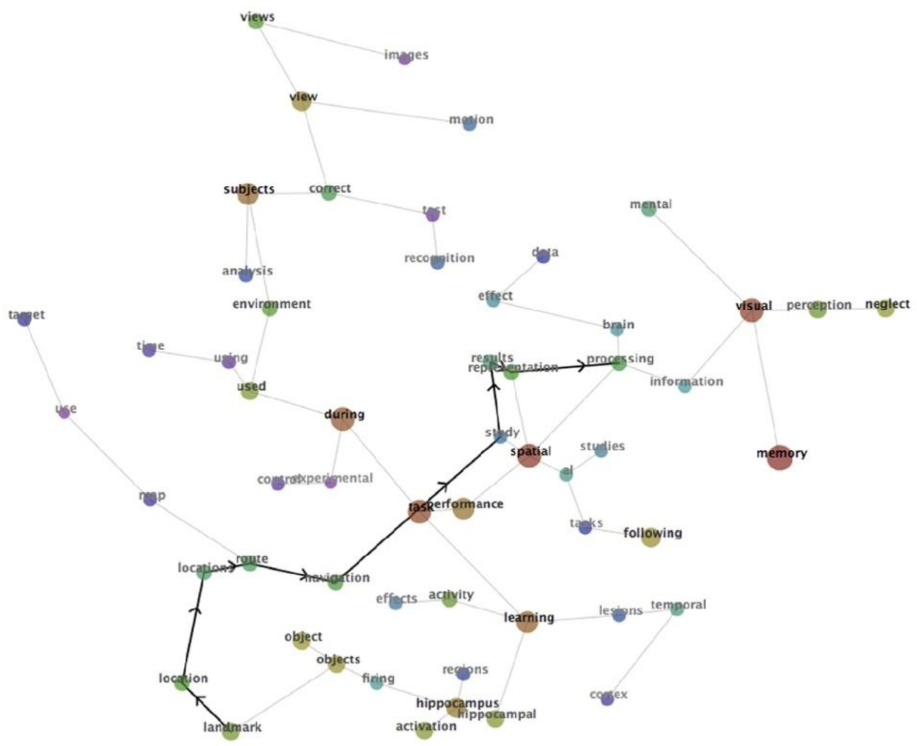


Figure 3. Concept Map with minimum spanning tree framework shown in light grey. A "knowledge pathway" is shown in black with arrows from the concept "landmark" to "processing".

Publications (including refereed conference papers)

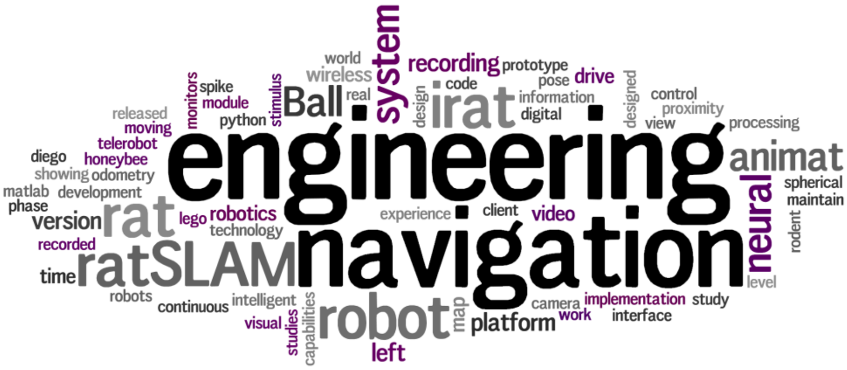
Stockwell, P., Colomb, R. M., Smith, A. E., Wiles, J. (2009) Use of an Automatic Content Analysis Tool: a Technique for seeing both Local and Global Scope. *International Journal of Human Computer Studies*, 67(5), 424-436.

Conference Abstracts

Stockwell, P., Smith, A. E., Wiles, J. (2009) Displaying a Framework in a Concept Map using Network Graph Techniques. In E. Banissi, et al (Eds.), Proceedings of the 13th International Conference on Information Visualisation (pp. 661-666). Barcelona, Spain: IEEE Computer Society.

Patents

Australian Provisional Patent application 2007906891. "Methods for Determining a Path", Stockwell, P., Smith, A. E. and Wiles, J.



Engineering, Technology and Robotics

Project Members

Chief Investigators	Janet Wiles, Gordon Wyeth, Mandyam Srinivasan
Engineer	David Ball
Collaborators	Michael Milford, Tien Luu, Allen Cheung, Peter Stratton, Francois Windels, Chris Nolan
PhD Student	Gavin Taylor
Research Assistants	Gavin Taylor (2009) Daniel Clarke (co supervised) (2009) Jack Valmadre (co supervised) (2009-2010)
Research Experience Students	Scott Heath (2008-2010), Ryan Wong (2008-2009), Chris Lehnert (2008-2009), Gavin Taylor (2008-2009) Nick Calver (2009-2010), Jessica Wrigley (2009-2010) Hilton Bristow (2009-2010), Ezra Zigenbine (2009-2010) Kieran Wynn (2009-2010)
Undergraduate Thesis Students	Scott Heath (2009), Marcel Giermanski (2009) Ryan Wong (2009), Chris Lehnert (2009) Nick Calver (2010), Jessica Wrigley (2010) Hilton Bristow (2010), YeHua Hsu (Mike) (2010) Shao-Kuang Fang (William) (2010), Daniel Clarke (2010)

Engineering, Technology and Robotics

David Ball

(July 2008 – November 2010)

Introduction

My primary role has been to enable new science through collaboration where I provide technology, systems and mechatronics engineering leadership to the Thinking Systems team. In this way I work with the researchers to evaluate and provide appropriate engineering planning and solutions. I also am working on new mechatronics solutions for mobile robots primarily focussed on building a new rat animat robot.

iRat (Intelligent Rat Animat Technology) (with Scott Heath)

The iRat (intelligent Rat animat Technology) is a rat animat robot designed for robotic and neuroscience teams as a tool for studies in navigation, embodied cognition, and neuroscience research (Ball, Heath, Wyeth, and Wiles, 2010, ACRA). The rat animat has capabilities comparable to the popular standard Pioneer DX robots but is an order of magnitude smaller in size and weight. The robot's volume is approximately $0.08m^2$ with a mass of 0.5kg and has visual, proximity, and odometry sensors, a differential drive, a 1 GHz x86 computer, and LCD navigation pad interface. To facilitate the value of the platform to a broader range of researchers, the robot uses the Player-Stage framework, and C/C++, Python, and MATLAB APIs have been tested in real time. Two studies of neural simulation for robot navigation have confirmed the rat animat's capabilities.

An industrial design company, Infinity Design, is currently styling the iRat to give a professional look suitable for commercialisation. They are also designing a dock to allow the iRat to recharge autonomously.

Figure 1. (left) iRat prototype. (right) iRat by Infinity Design

In 2010, three undergraduate thesis projects were based around the iRat.

- Development of a whisker system to sense proximity and texture - Nick Calver.
- Development of a visual obstacle avoidance system - Daniel Clarke.
- Initial work on developing legs for a future quadruped version – Jessica Wrigley.

RatSLAM on the iRat (with Scott Heath, Michael Milford)

This study ran RatSLAM on the iRat to map a figure of eight environment which demonstrated the capabilities of the iRat (Ball, Heath, Milford, Wyeth, Wiles, 2010, Artificial Life).

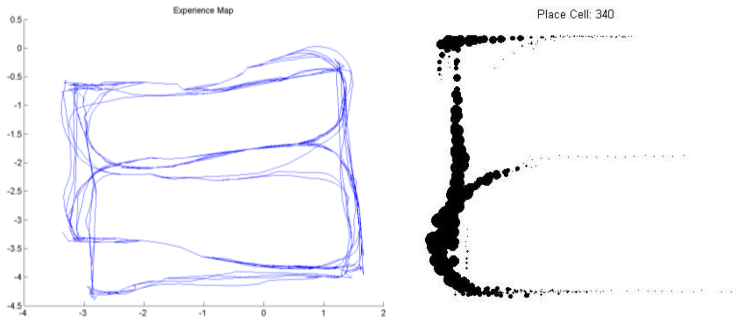


Figure 2. (left) RatSLAM experience map, (right) 'non conjuctive grid cells' cells generated from the pose cells.

Spike Time Robotics (with Peter Stratton, Christopher Nolan)

In this study a spiking network controls the iRat in real time (Wiles, Ball, Heath, Nolan and Stratton, 2010, ICONIP). The study demonstrates how the neural controller directs the rat animat's movement towards temporal stimuli of the appropriate frequency using an approach based on Braitenberg Vehicles. The circuit responds robustly (after four cycles) when first detecting a light pulsing at 1 Hz, and rapidly (after one-to-three cycles) when primed by recent experiences with the same frequency. This study is the first to demonstrate a biologically-inspired spike-based robot that is both robust and rapid in detecting and responding to temporal dynamics in the environment. It provides the basis for further studies of biologically-inspired spike-based robotics.

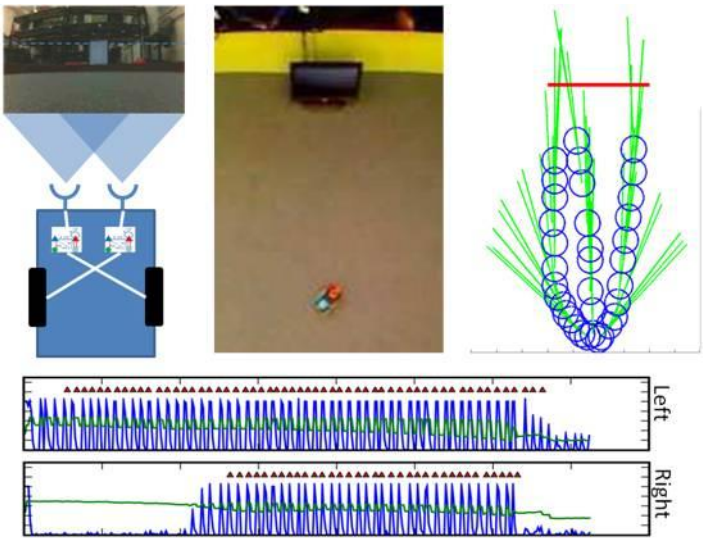


Figure 3 - iRat location and spiking network output while tracking a 1Hz flashing stimulus. (top left) iRat showing two light sensors, their respective resonant circuits and crossed connections to the wheels. (top middle) Tracking camera view. (top right) Tracking data showing three trials, first with the robot directly facing the flashing stimulus, then rotated approximately 45° to the left and right. (bottom) Left and right sensor responses (see text for details).

Blind Bayes (with Allen Cheung, Michael Milford)

Real rodents are able to maintain localisation even when visually deprived. This study is investigating the iRat's ability to maintain localisation with only sensory information about the walls in close proximity. (Cheung, Ball, Milford, Wyeth and Wiles. In preparation.)

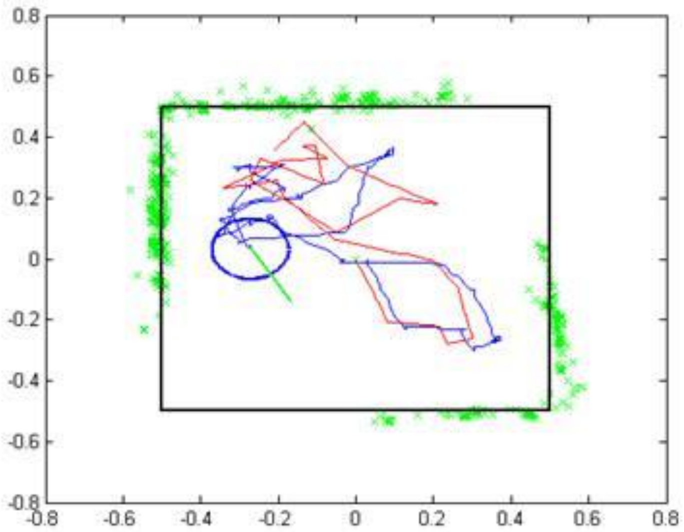


Figure 4. iRat global pose tracked overhead (blue line), integrated wheel odometry (red line) and sensory wall measurements (green crosses). The goal is to maintain accurate global pose by resetting the iRat's internal map position when colliding with the wall.

RatSLAM – MATLAB version (with Michael Milford, Scott Heath)

There was motivation for a lightweight version of RatSLAM:

- that could be released publically,
- that SLAM researchers could use on their own datasets, and
- a tool to understand how the RatSLAM algorithm works.

MATLAB was chosen for a version that could be publically released due to its inbuilt functions for matrix operations, graphing, and loading video. The result was a lightweight implementation that clearly shows the major functionality of RatSLAM including: View Templates, Pose Cells and Experience Map. The core parts of the RatSLAM have also been written in C and are loaded as a DLL which allows much faster processing. A module is also available to process overhead images to track global pose. The code supports as an input:

- processing a combination of video and wheel odometry information from files (such a recorded from a robot) , or
- processing video and performing visual odometry (such as recorded from a moving platform like a car), or
- real time closed loop control of a robot using *Player-Stage*.

The code for the offline versions is online at http://ratslam.itee.uq.edu.au/ along with two datasets: a partial St Lucia suburb video and a partial Axon level 5 video. The real time version will be released soon.
Work has begun on integrating a GPU version of RatSLAM into the MATLAB code base. Due to the parallel nature of the GPU this will be much faster.

A technical report is in preparation.

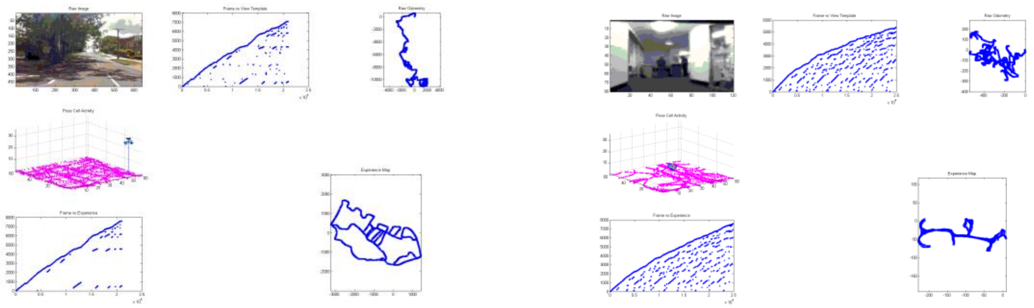


Figure 5. - St Lucia (left) and Axons level 5 (right) using visual odometry using a MATLB version of RatSLAM.

Omni-directional drive robot platform (with Chris Lehnert)

This project designed a robot research platform with high mobility that can traverse typical office environments and has decent onboard computational resources. (Ball, Lehnert, and Wyeth. 2010. ICRA.) A novel spherical drive mechanism has been designed and tested. The advantage of this spherical drive mechanism is continuous contact with the ground plane to reduce vibration and isotropic rotational characteristics that facilitate improved traversal properties. In 2010 two undergraduate projects worked on turning the drive system into an autonomous robot and adding the ability to autonomously recharge.

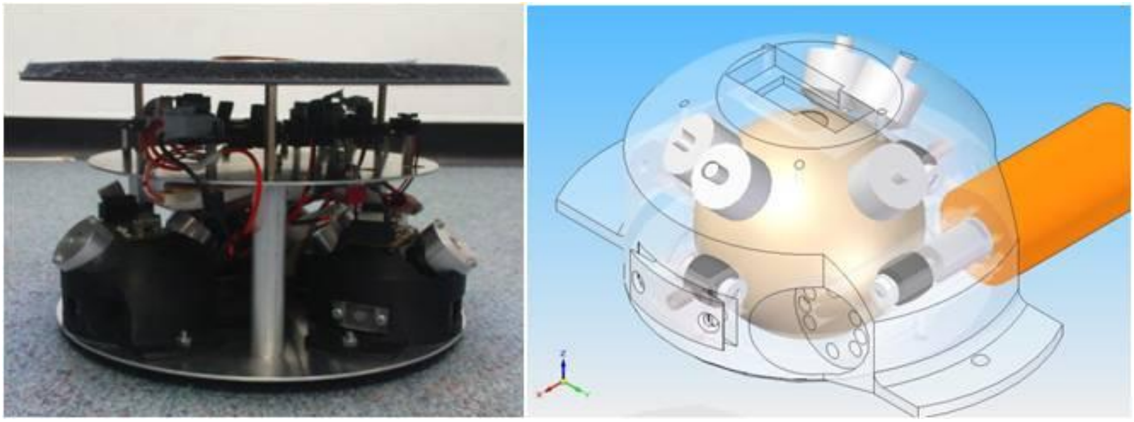


Figure 6. (left) Prototype omnidirectional drive robot. (right) A CAD drawing of the spherical mechanism.

Telerobot for RatSLAM (with Scott Heath)

A telerobot, is a telepresence device that allows a user to interact with a robot over the internet. There are few active public telerobots on the internet. In general, direct control of the robot is not appropriate because of the communication lag and the ratio of users to robots. The RatSLAM navigation system allows the user to indirectly control the robot by setting navigation goals. A generic streaming and interaction module has been written for the Apache web server which communicates with the robot and an Adobe Flash client in the user's browser. In the current implementation it allows the user to set navigation goals while the robot's camera, internal (RatSLAM experience) map, etc is streamed.

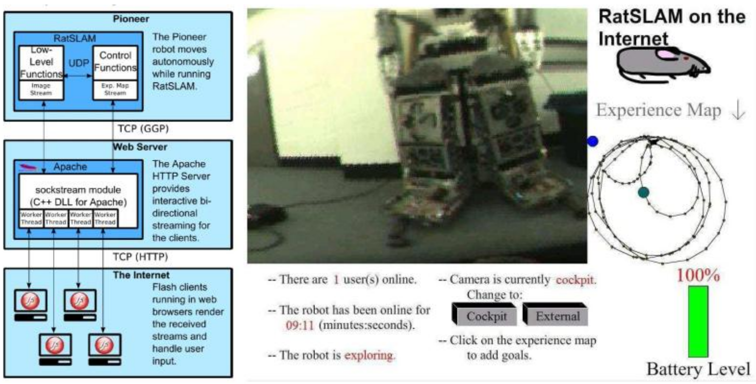


Figure 7. (left) The telerobot architecture showing the connection between the pioneer, the webserver and the user's client. (right) The flash client interface showing the robot's camera view, map, battery charge level, etc. Users can click on the map to add navigation goals (shown as a green dot).

Insect environment replication - Multi-monitor world (with Tien Luu, Allen Cheung, Gavin Taylor)

Neuroscientists investigate honeybee flight behaviour using visual stimulus. (Luu, Cheung, Ball, and Srinivasan. Journal of Experimental Biology. - corrections.) Initial investigations demonstrated that moving an object on an LCD past a Bee resulted in changes to the angle of the Bee's abdomen. This investigation prompted the development of a setup that would allow a virtual world to be rendered on monitors surrounding the honeybee. My solution was a multithreaded C++ DirectX application that could render a viewport on each monitor. Objects can be rendered relative to the world coordinates or the camera. This system works with up to 6 monitors @ 1920 x 1200 pixels @ 60 Hz. A Python interface was added so that the biologists could adjust major settings such as the number of windows, the textures and planes, the position and velocity of the camera and the platform. A LEGO platform was constructed that can raise and lower on command from the python script.

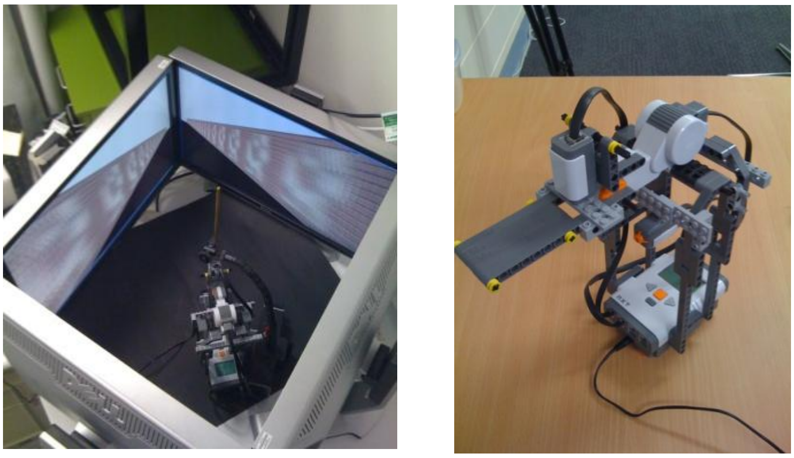
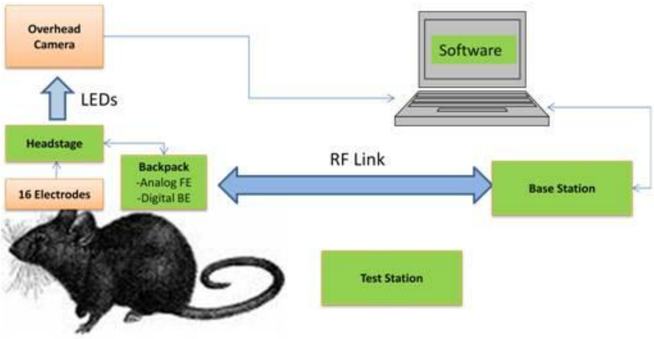


Figure 8. (left) Four monitors with moving scene surrounding the Bee tether and LEGO platform. (right) The LEGO platform from another angle.

Rodent Electrophysiology
Digital Wireless Neural Telemetry Phase One (with Ryan Wong, Francois Windels)

Typically, electrophysiologists tether the rodent to their neural recording equipment. A wireless neural recording system would allow for: larger and more complex environments, social interaction studies, and outdoor recordings. Existing wireless rodent recording systems can be classified by the number of channels, recording rate, bit precision, continuous streaming versus spike only, size, weight, battery life, and cost.
A prototype has been developed that allows for continuous digital recording from 16 channels @ 20kHz @ 8 bits, weighs less than 50 grams and lasts over one hour. The prototype has recorded spikes from a freely behaving rodent with comparable results to a tethered system.



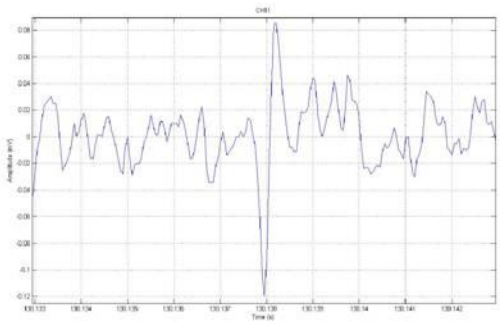


Figure 9. (left) Digital wireless neural recording system architecture. (right) Data recorded using the digital wireless neural recording system from a freely behaving rodent showing a neuron spike.

The wireless module is enabling a novel experiment to be setup which is currently in progress. Scott Heath has begun work on a Rat Tracking program suitable for the novel environment.

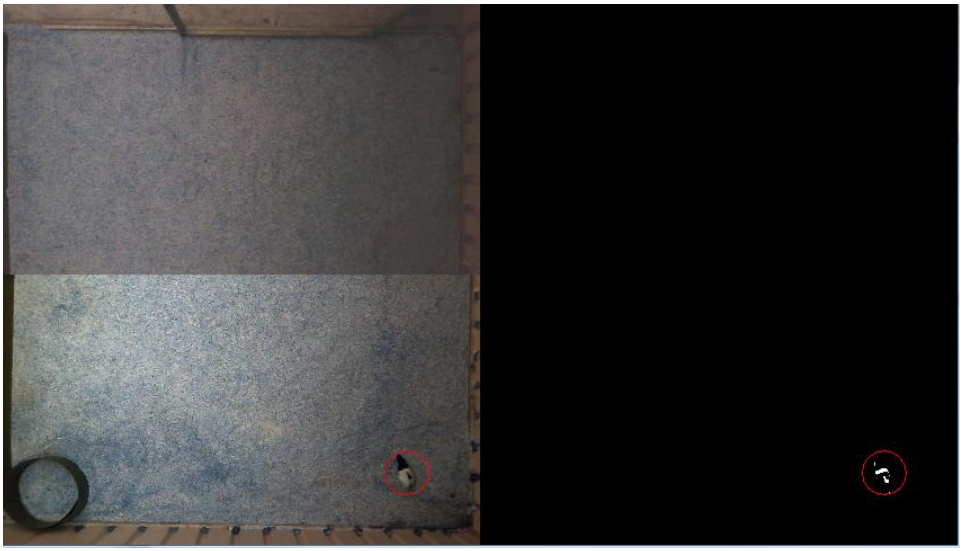


Figure 10. Rat been tracked in a new novel environment.

Digital Wireless Neural Telemetry Phase Two (with Tara Hamilton, Bala Thanigaivelan)

Work has begun on designing the next phase module uses a custom IC to replace the analogue components which make up over 50% of the area and power. The IC is a challenge in itself due to the high gain requirements. The first iteration of the chip has some problems with stability but an updated version will be resubmitted soon.

Publications

Ball, D. (2008) Adaptation by Prediction: Reading the Play, Postgraduate Thesis, The University of Queensland.

Ball, D., Wyeth, G.F. (2008) Reading the Play – Adaptation by Prediction of Agent Motion, Proceedings of the 2008 Australasian Conference on Robotics and Automation (ACRA), Canberra, Australia.

Ball, D., Heath, S., Wyeth, G.F., Wiles, J, (2010) iRat: Intelligent Rat Animat Technology, Proceedings of the 2010 Australasian Conference on Robotics and Automation (ACRA), Brisbane, Australia.

Ball, D., Heath, S., Milford, M.J., Wyeth, G.F., Wiles, J. (2010) "A Navigating Rat Animat", in proceedings of the International Conference on Artificial Life, Odense, Denmark.

Ball, D., Lehnert, C., Wyeth, G.F.(2010) A Practical Implementation of a Continuous Isotropic Spherical Omnidirectional Drive, Proceedings of the International Conference on Robotics and Automation (ICRA), Anchorage, Alaska.

Wiles, J., Ball, D., Heath, S., Nolan, C., Stratton, P. (2010) Spike-Time Robotics: A Rapid Response Circuit for a Robot that Seeks Temporally Varying Stimuli, 17th International Conference on Neural Information Processing (ICONIP) (accepted).

Papers in Preparation

Cheung, A., Ball, D., Milford, M., Wyeth, G.F., Wiles, J. Blind Bayes in a Box: Rat and Robot Navigation in the Dark.

Luu, T., Cheung, A., Ball, D., Srinivasan, M.V. Honeybee flight: A novel streamlining response, The Journal of Experimental Biology (corrections).

Conference

Luu, T., Cheung, A., Ball, D., Srinivasan, M.V. (2010) “Honeybee flight: a novel ‘streamlining’ response,” Poster: 9th International Congress on Neuroethology.

Thanigaivelan, B., Ball, D., Wiles, J., Hamilton, T. (2010) An 8-channel neural recording system with programmable gain and bandwidth, 2nd Asia-Pacific Signal and Information Processing Association (APSIPA) (accepted).

Related Activities

Course coordinator for METR4202 in 2010 – Advanced Control and Robotics (65 students) and co-lecturer for METR3800 in 2010 – Mechatronics Design Project (30 students) and lecturer for COMP4001 in 2009 (1 student).

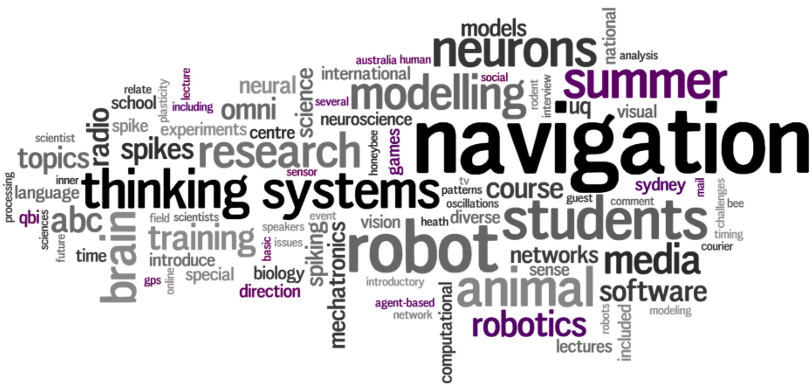
Presentation: A Rat Animat at the “James S. McDonnell Foundation Adult Neurogenesis Consortium Meeting”, San Diego, USA in May 2010

Workshop: A Rat Animat at the “Temporal Dynamics and Learning Centre”, San Diego, USA in May 2010

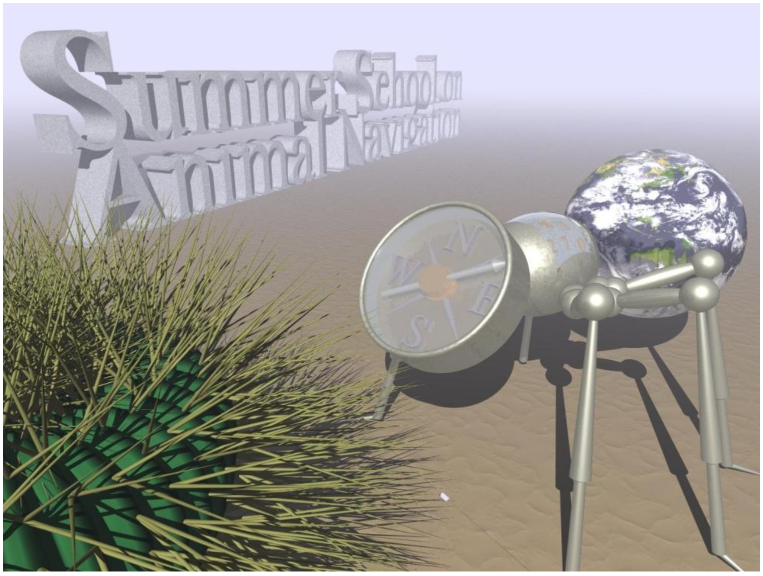
Presentation: Thinking Systems: Engineering “collaborations between engineers and neuroscientists” at the “James S. McDonnell Foundation Adult Neurogenesis Consortium Meeting”, San Diego, USA in May 2009

Recruitment and close supervision of RAs and research scholars for the various postdocs and themes:

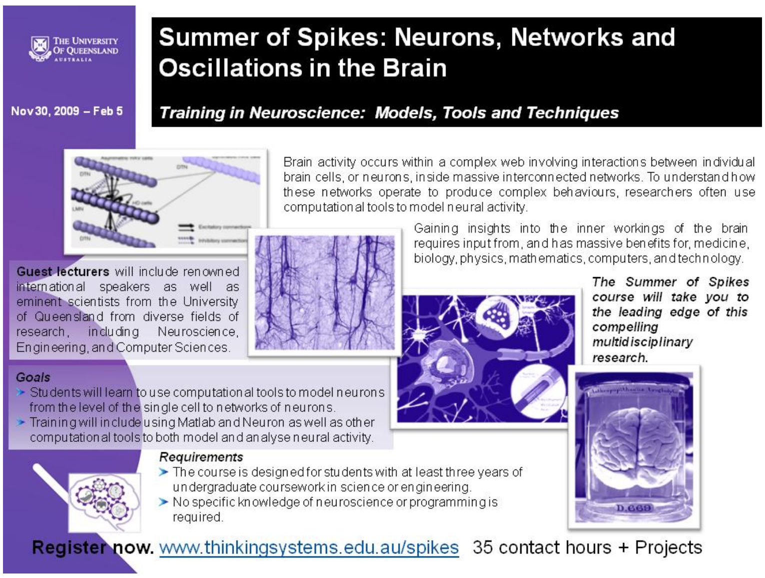
- Robert Ninness: Assisted Francois Windels by building microdrives and other associated electrophysiology equipment.
- Justin Cappadonna: Assists Tien Luu by performing Bee electrophysiology experiments.
- Daniel Clarke: Assisted Oliver Baumann by adapting the fMRI barrel world to add interference.
- Jack Valmadre: Assisted Oliver Baumann by developing a new fMRI world to investigate head direction in humans.
- Scott Heath: iRat software platform.



Related Activities: Training, Media and Publications



Cataglyphis roboticus



Special Summer School on Animal Navigation

23 -27 November, 2009

Jointly organized and sponsored by: ARC Centre of Excellence in Vision Science/Centre for Visual Sciences and Thinking Systems/COSNet (UQ).

The “Summer School on Animal Navigation” was held for the first time at UQ in 2009. On this occasion, it was jointly organized by Thinking Systems (UQ) and the ARC Centre of Excellence in Vision Science (ACEVS) / Centre for Visual Sciences (CVS). The event organization was coordinated by Allen Cheung (TS) and involved many members of TS, as well as other QBI research and administrative staff.

Participants at the 2009 Summer School

Since its inception eight years earlier, the goal of the “Summer School on Animal Navigation” has been to introduce students from Australia, New Zealand and other countries to the fascinating and rapidly developing multi-disciplinary research field of “Animal Navigation”. The mechanisms of animal navigation continue to be a hot research topic internationally, in biology and in robotics.

The event has provided a forum where a diverse range of animal species are discussed in interactive presentations to illustrate the many challenges, physiological adaptations, and computational principles used in nature to carry out various navigation tasks.

In 2009, topics included: principles, concepts and key experiments in animal and robot navigation; sensory physiology, neurobiology, neurocomputational models, from arthropods to mammals; landmark guidance, view-based homing, path integration, odometry, optic flow processing and biological compasses; diverse challenges and solutions of microbial to transcontinental navigation; basic and advanced topics in neuro-ethological robots.

During the week, participants saw and participated in live demonstrations of animal and robot experiments in the laboratory. Speakers and students also took part in animal and human field navigation experiments.

(Left) Human navigation: blindfolded, with GPS backpack.
(Right) Differential GPS.

The invited speakers included leading researchers from the United States, Germany, Israel, New Zealand and Australia.

Lecture Series and Special Topics Course

Summer of Spikes: Neurons, Networks and Oscillations in the Brain

Training in Neuroscience: Models, Tools and Techniques Nov 30 2009 - Feb 3 2010

The Summer of Spikes course was designed to introduce the fundamentals of spiking activity in neurons and computational modelling of spiking neurons, both individually and in networks. The course was multidisciplinary, involving introductory lectures and guest lecturers from national and international scientists from diverse fields of research, including neuroscience, engineering, and computer science. Topics covered a range of issues focussed on individual neurons and their modelling, and on the dynamics of networks of neurons and their modelling. Introductory Lectures and Tutorials were given by the course organisers Angelique Paulk, Peter Stratton, and Janet Wiles.

Guest lecturers included:

Pankaj Sah
“What are synapses and what is synaptic plasticity?”

Francois Windels
“How do we relate network models to the biology of the brain?”

Bruno van Swinderen
“How do we relate these approaches to understanding an area of the brain?”

Jean-Marc Fellous
“Basic issues in neural data analyses: Finding patterns.”
“Neuromodulatory power... same neurons, different functions.”
“It's time for spikes! Spike timing and spike patterns”

Guy Wallis
“Categorisation and generalisation using self-organising, competitive neural systems”

Anthony Burkitt
“Spike Timing Dependent Plasticity and the formation of network structure”

Michael Breakspear
“Populations of spiking neurons: From bifurcations to moments and hierarchies”

David Reutens
"Abnormal Spikes"

Benedikt Grothe
“Time and the Brain”

Training

Honours/MSc Students:

Bristow, Hilton (ITEE 2010)
Calver, Nicholas (ITEE 2010)
Clarke, Daniel (ITEE 2010)
Fang, William (ITEE 2010)
Hsu, Mike (ITEE 2010)
Wrigley, Jessica (ITEE 2010)
Marcel Giermanski (ITEE 2009)
Jacinta Fitzgerald (ITEE 2008)
Andrew Schrauf (ITEE 2008)
Andreas Sanin (ITEE 2007)

Student Scholars

The scholarships allowed us to give the students the opportunity to experience a research environment, mentor and evaluate students for future higher research with the Thinking Systems group, and achieve research support outcomes.

Summer 2009 - 2010 Students

SS09-01 Omni Robot - Docking and Power System (Robotics) – Kieran Wynn
SS09-02 Omni Robot - Omni Vision System (Software) – Joel McGrath
SS09-03 Omni Robot - Drive and Sensor System (Electrical) – Jessica Wrigley and Ezra Zigenbine
SS09-04 Omni Robot - Navigation and Behaviours (Mechatronics or Software) – Hilton Bristow
SS09-06 Robot Rat (Mechatronics) – Scott Heath
SS09-07 Rodent Whisking (Mechatronics) – Nick Calver
SS09-09 Automatic Behavioural Analysis (Software) – Tim Martin
SS09-10 Navigation for a High Speed Outdoor Robot (Robotics) – Daniel Clarke
SS09-11 Boxed In (Modelling) – Kieran McLean
SS09-18 Adding objects to spatial language games (AI) - Elizabeth Alpert

Winter 2009 Students

WS09-01 Mobile Robot Sensor System (Robotics) – Ezra Zigenbine
WS09-06 Modelling Spiking Neurons (Modelling) – Nabeelah Ali
WS09-07 Deconstructing a Squiggle (Modelling) – Benjamin Sinclair
WS09-10 Enriching social interactions for robot language games (Software, agent-based modelling) - Elizabeth Alpert

Summer 2008-2009 Students

SS08-01 Omni-directional drive robot research platform (Robotics) – Chris Lehnert
SS08-02 Digital wireless telemetry for neural recording (Electronics, Signal Processing) – Ryan Wong
SS08-03 Interactive web interface for robots (Robotics, Networking) – Scott Heath
SS08-04 Environment replication for insects (Mechatronics, 3D Graphics) – Gavin Taylor
SS08-06 Large Text Corpus (General) – Andrew Jones
SS08-09 Aggressive Bee Model (Computational Modelling) (QBI) – Timothy Mews

SS08-10 Enriching social interactions for robot language games (Software, agent-based modelling) – Elizabeth Alpert

SS08-12 Rodent Neural Recordings (Electrophysiology) (QBI) – Robert Ninness

Summer 2007-2008 Students

Steven Langsford

Media Training

A media awareness session was organised for Thinking Systems researchers and students on 21st January 2010, run by the UQ Office of Marketing and Communications and featuring training in the Videovision TV studio.

Media Coverage

O. Baumann. Australian Geographic: “Sense of direction can be learned” (08.10.2010) http://www.australiangeographic.com.au/journal/sense-of-direction-can-be-learned.htm

O. Baumann. Queensland Brain Institute scientists find the brain's inner compass. Courier Mail. http://www.couriermail.com.au/news/queensland/queensland-brain-institute-scientists-find-the-brains-inner-compass/story-e6freoof-1225931978553

O. Baumann. ABC Online: “Study locates our sense of direction” (30.09.2010) http://www.abc.net.au/science/articles/2010/09/30/3025268.htm

O. Baumann. CBC Online: “Brain’s sense of direction located” (30.09.2010)http://www.cbc.ca/technology/story/2010/09/30/direction-brain.html

O. Baumann. Daily News and Analysis: “How our brains ‘light up’ when we navigate” (30.09.2010) http://www.dnaindia.com/scitech/report_how-our-brains-light-up-when-we-navigate_1445632

O. Baumann. Courier Mail: “Magnetic personality or not, we all have an inner campus” (30.09.2010).

O. Baumann. Sydney Morning Herald: “Mapping the brain” (30.09.2010).

O. Baumann. 702 ABC Sydney Radio Interview (30.09.2010).

O. Baumann. 91.7 ABC Coast FM Radio Interview (30.09.2010).

O. Baumann. Sydney Morning Herald: “Mapping the brain” (30.09.2010).

A. Cheung. Comment in New Scientist about new article: Souman, J., Frissen, I., Sreenivasa, M. and Ernst, M. (2009) “Walking straight into circles,” Current Biology. 19: 1-5. http://www.newscientist.com/article/dn17658-we-cant-help-walking-in-circles.html

A. Cheung. Comment in ABC Science about new article: Lent, D., Graham, P. and Collett, T. (2010) “Image-matching during ant navigation occurs through saccade-like body turns controlled by learned visual features,” Proceedings of the National Academy of Science USA 107(37): 16348-16353. http://www.abc.net.au/science/articles/2010/09/02/2997444.htm

T. Luu. Helped the SBS /BBC film crew (Stefan Moore, producer) shoot tethered honeybee flights. The movie clip was used in the “Honeybee Blues” documentary shown in Qantas iQ Inflight documentaries. Credited as “Bee wrangler”.

M. Milford. 19 February, 2009, TV: ABC Catalyst. http://www.abc.net.au/catalyst/stories/2494845.htm

M. Milford. October 2008, Magazine: New Scientist Magazine. http://www.newscientist.com/article/mg20026765.300-rat-brains-show-robots-the-way.html

M. Milford. June 2007, Radio: ABC Radio http://www.abc.net.au/queensland/conversations/stories/s1943051.htm

M. Milford. Several dozen articles in international, national and regional newspapers and magazines including The Australian Newspaper and Defence Technology International. Several radio station interviews.

J. Wiles. Brisbane Times. 2009 Space Odyssey: Brisbane maps robotic future. November 18 2009.

International Links

Professor Michael Arbib. University of Southern California USC Brain Project. Visited in November 2009. Host: Prof Janet Wiles.

David Ball, Janet Wiles. Presentation: A Rat Animat at the "James S. McDonnell Foundation Adult Neurogenesis Consortium Meeting", San Diego, USA in May 2010.

David Ball, Janet Wiles. Workshop: A Rat Animat at the "Temporal Dynamics and Learning Centre", San Diego, USA in May 2010.

David Ball, Janet Wiles. Presentation: Thinking Systems: Engineering "collaborations between engineers and neuroscientists" at the "James S. McDonnell Foundation Adult Neurogenesis Consortium Meeting", San Diego, USA in May 2009.

James Bonaiuto is a computational modeller working the Neural Simulation Language (NSL) from Michael Arbib's lab at the University Southern California, visited in March 2008. "Towards an Integrated Neural Modeling Environment: Bridging between Simulation and Experiment".

Professor Anthony Burkitt. Visited in January 2010. Host: Dr Peter Stratton.

Allen Cheung. 14th Dec 2007 - Gatsby Computational Neuroscience Unit (visit with Peter Dayan), UCL (+ presentation).

Allen Cheung. 15th Dec 2007 - Institute of Cognitive Neuroscience (visit with Neil Burgess), UCL.

Professor Jeffrey L. Elman. Department of Cognitive Science, University of California, San Diego. Attended the Thinking Systems Symposium on 22 November 2010.

Professor Jean-Marc Fellous. Visited in January 2010. Host: Dr Angelique Paulk.

Professor Benedikt Grothe. Visited in February 2010. Host: Prof Mandyam Srinivasan (Qld Brain Institute).

Associate Professor Robert Mahony, Faculty of Engineering and Information Technology, Australian National University, Canberra, Australia. February and October 2010.

Michael Milford. Visit to the laboratory of Associate Professor Robert Mahony, Faculty of Engineering and Information Technology, Australian National University, Canberra, Australia. February 2010.

Michael Milford. Visit to the laboratory of Professor Edvard Moser and Professor May-Britt Moser, Kavli Institute for Systems Neuroscience and Centre for Biology for Memory, Norwegian University of Science and Technology, Trondheim, Norway, March 2008.

Michael Milford. Visit to laboratories of Professor Neil Burgess and Professor John O'Keefe, University College London Institute of Cognitive Neuroscience, London, United Kingdom, March 2008.

Michael Milford. Visit to the laboratory of Dr Andrew Davison, Department of Computing, Imperial College London, March 2008.

Michael Milford. Visit to the laboratory of Professor Keith Downing, Department of Computer and Information Sciences, Norwegian University of Science and Technology, March 2008.

Professor Rafael Nunez, Cognitive Science Dept, UCSD visited in February 2008. "The embodied nature of human abstraction: The empirical investigation of spatial construals of time.

Visit from Dr Robert Oates, Sch. of Computer Science and IT, University of Nottingham, Nottingham, United Kingdom 2008.

Professor John O'Keefe. University College London. Attended the Thinking Systems Retreat, Couran Cove Resort, 18-21 April 2010.

Peter Stratton. Visited and presented at University College London, December 2007. "Comparing Kurtosis Score to Traditional Statistical Metrics for Characterizing the Structure in Neural Ensemble Activity".

Francois Windels. June 2009, Visit to Matthew Wilson laboratory, Picower institute, MIT.

Project Retreats and Symposia

Thinking Systems Retreat, Couran Cove Resort, 18-21 April 2010
Thinking Systems Joint Symposium, Queensland Brain Institute, 17-18 November, 2009
Thinking Systems Retreat, O‘Reilly‘s, 8-11 June 2009
Thinking Systems Workshop, Queensland Brain Institute, 27 November 2008
Thinking Systems Retreat, O‘Reilly‘s, 5-7 June 2008
Thinking Systems Workshop, Queensland Brain Institute, 17 January 2008
Weekly meetings started 1st February 2007
Thinking Systems 1st Grant Meeting, Noosa, 15 August 2006

Publications

Book

Milford, M.J. (2008) *Robot Navigation From Nature*, Springer Tracts in Advanced Robotics, Springer-Verlag.

Book Chapters

Angus, D. (2009) Niching for Ant Colony Optimisation. Biologically-Inspired Optimisation Methods: Parallel Algorithms, Systems and Applications. Lewis, A.; Mostaghim, S. & Randall, M. (ed.). Springer.

Cheung, A. (2009) "Mathematical and neural network models of medium range navigation during social insect foraging," In: *Jarau and Hrncir* (eds.) Food Exploitation by Social Insects: Ecological, Behavioral, and Theoretical Approaches. Taylor & Francis Group LLC.

Cheung, A. (2008) "From behaviour to brain dynamics," in: Marinaro M., Scarpetta S. and Yamaguchi Y. (Eds) Dynamic Brain – from Neural Spikes to Behaviors, Lecture Notes in *Computer Science*, vol 5286, pp91-95. Springer Berlin / Heidelberg.

Magnussen S., Greenlee M.W., Baumann O., Endestad T. (2010) Visual perceptual memory - anno 2008. In: *Memory, aging and the brain*. Bäckman L, Nyberg L, eds. London: Psychology Press .

Stratton, P., Wiles, J. (2008) Comparing Kurtosis Score to Traditional Statistical Metrics for Characterizing the Structure in Neural Ensemble Activity. In M. Marinaro et al., editors, Dynamic Brain – from Neural Spikes to Behaviors, Springer LNCS V 5286, 115-122.

Wyeth, G.F., Milford, M.J., Schulz, R., Wiles, J. (2010) "The RatSLAM project: robot spatial navigation", in Neuromorphic and Brain-Based Robotics, Cambridge University Press, in press.

Journal Articles

Angus, D., Woodward, C. (2009) Multiple Objective Ant Colony Optimisation. *Swarm Intelligence*, 3, 69-85

Baumann, O., Mattingley J.B. (2010b) Medial parietal cortex encodes perceived heading direction in humans. *Journal of Neuroscience* 30: 12897-12901.

Baumann, O., Mattingley, J.B. (2010a) Scaling of neural responses to visual and auditory motion in the human cerebellum. *Journal of Neuroscience* 30: 4489-4495.

Baumann O., Chan, E., Mattingley, J.B. (2010) Dissociable neural circuits for encoding and retrieval of object locations during active navigation in humans. *NeuroImage* 49:2816-2825.

Baumann, O., Belin, P. (2010) Perceptual scaling of voice identity: common dimensions for different vowels and speakers. *Psychological Research* 74: 110-120.

Baumann, O., Greenlee, M.W. (2009) Effects of attention to auditory motion on cortical activations during smooth pursuit eye tracking. *PLoS ONE* 4:9.

Baumann, O., Endestad, T., Magnussen, S., Greenlee, M.W. (2008) Delayed discrimination of spatial frequency for gratings of different orientation: behavioral and fMRI evidence for low-level perceptual memory stores in early visual vortex. *Experimental Brain Research* 188:363-369.

Cheung, A. (2010) "The fourth moment of the radial displacement of a discrete correlated/persistent random walk," *Journal of Theoretical Biology.* 264: 641-644.

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Professor Perry Bartlett was appointed Foundation Chair in Molecular Neuroscience at The University of Queensland in August 2002, and as Foundation Director of the newly established Queensland Brain Institute in 2003.

Professor Bartlett previously headed the Neuroscience division at the Walter and Eliza Hall Institute in Melbourne, and is a Fellow of the Australian Academy of Science and the recipient of the highly prestigious ARC Federation Fellowship. His group's work on the production of neurons in the adult brain has been published on the front cover of Nature and now focuses on how new neurons regulate higher-brain functions such as memory and learning.

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Professor Kevin Burrage is a Federation Fellow (2003-2010). He has joint positions in Mathematics and the Institute for Molecular Bioscience. He is Professor of Computational Mathematics at the University of Queensland.

His areas of interest include multi-scale modelling, scientific parallel and grid computing, mathematical software, modelling in the biological sciences, numerical solution of differential equations (deterministic and stochastic), linear systems of equations, computational biology, engineering applications.

Professor Geoffrey Goodhill

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Professor Goodhill did a Joint Honours BSc in Mathematics and Physics at Bristol University (UK), followed by an MSc in Artificial Intelligence at Edinburgh University and a PhD in Cognitive Science at Sussex University. Following a postdoc at Edinburgh University he moved to the USA in 1994, where he did further postdoctoral study in Computational Neuroscience at Baylor College of Medicine and the Salk Institute. Professor Goodhill formed his own lab at Georgetown University in 1996, where he was awarded tenure in the Department of Neuroscience in 2001. In 2005 he moved to a joint appointment between the Queensland Brain Institute and the School of Mathematical and Physical Sciences at the University of Queensland.

Professor Goodhill is currently Editor-in-Chief of the journal "Network: Computation in Neural Systems".

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Professor Jason Mattingley is Foundation Chair of Cognitive Neuroscience at UQ, where he holds a joint appointment between the Queensland Brain Institute and School of Psychology. He received his PhD in neuropsychology from Monash University in 1994, and subsequently spent several years as a research fellow in Cambridge, England, where he was also elected a Fellow of King's College.

His research spans the broad field of cognitive neuroscience, with particular emphasis on the behavioural effects of brain injury caused by stroke. His research team also employs brain imaging and brain stimulation techniques to investigate various aspects of cognition in healthy individuals. Professor Mattingley's work has helped to elucidate the cognitive and neural mechanisms underlying selective attention and motor control. He has published more than 100 articles in scholarly journals, including numerous papers in Nature, Science and Nature Neuroscience.

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Professor Pankaj Sah is a neurobiologist and head of Synaptic Plasticity at the Queensland Brain Institute. He graduated in Medicine from the University of NSW in 1983. Following an internship, he became interested in the brain and did a PhD in neuroscience. After completing his PhD, he worked in the United States for two years and returned as a postdoctoral fellow to the University of Queensland for an initial three years. He then moved to the University of Newcastle, Faculty of Medicine. In 1998, he set up a lab at the John Curtin School of Medical Research in Canberra, and relocated to QBI as a founding member in 2003.

His lab works on the amygdala, a region of the brain involved in laying down emotional memory. Pankaj became interested in working on the amygdala as dysfunction of this structure underlies mental disorders such as panic attacks, anxiety and post-traumatic stress disorder.

Chief Investigators

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Andrew Smith is the creator of Leximancer, a software application for text analysis. His early research training was in Physics, with a Ph.D. from The University of Queensland in 1993. From 1993 to 2000 Andrew worked in the IT industry mostly in positions where he has worked closely with users.

In 2000 he undertook a research Masters degree in Information Science in order to develop a robust computational system for quantifying and visualising the conceptual information in large text collections.

He is now working on new ways to visualise and quantify the temporal dynamics of communication with the Thinking Systems team at UQ, as well as an automated document library system for use in various criminal intelligence applications with a team from ISSR. He will continue to play a leading role in driving the Leximancer technology forward as Chief Scientist of Leximancer Pty Ltd.

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Professor Mandyam Srinivasan moved to the University of Queensland in January 2007 to take up a Professorship in Visual Neuroscience at the Queensland Brain Institute. In August 2007, he was awarded the Queensland Smart State Premier's Fellowship. Before coming to UQ, Professor Srinivasan headed a 20-strong team at the Australian National University where – for more than two decades – his laboratory produced some 180 publications, including 21 in high-impact journal articles in publications such as Nature, Science, PNAS, PLOS Biology and Current Biology.

By studying the behaviour of small animals, such as insects, Professor Srinivasan and his colleagues have demonstrated that many relatively simple nervous systems nevertheless display a rich behavioural repertoire. The Srinivasan laboratory seeks to elucidate principles of flight control and navigation, and to explore the limits of the 'cognitive' capacities of small brains.

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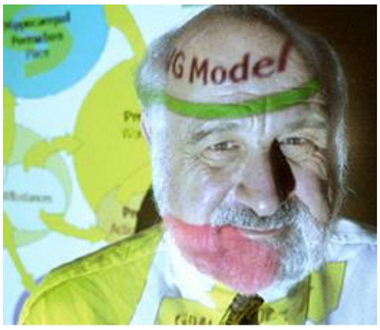
Professor Gordon Wyeth recently joined the Queensland University of Technology as a Professor in robotics. He holds a PhD and a Bachelor of Engineering degree (with honours) in Computer Systems Engineering. He is the President of IEEE Control Systems, Robotics and Automation Queensland chapter, former president of the Australian Robotics and Automation Association and has served in various leadership positions in the RoboCup International Federation. He serves in various editorial positions for leading international robotics journals and conferences.

Professor Wyeth's research receives funding through the Australian Research Council and other government and industry bodies. His team has designed and constructed more than twenty types of robots, including flying robots, wall-climbing robots, high performance wheeled robots, legged robots, manipulators and a humanoid robot. His robot soccer team, the RoboRoos, have been runners-up three times in the RoboCup World Cup of robot soccer. His research is internationally recognized for building practical and useful robots that exploit, explain and expand models of living systems.

International Partner Investigators

Professor Michael Arbib



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Professor Michael Arbib has led international research in computational neuroscience for three decades. He is Professor of Computer Science, as well as a Professor of Biological Sciences, Biomedical Engineering, Electrical Engineering, Neuroscience and Psychology at the University of Southern California (USC).

The thrust of Michael Arbib's work is expressed in the title of his first book, Brains, Machines and Mathematics (McGraw-Hill, 1964). The brain is not a computer in the current technological sense, but he has based his career on the argument that we can learn much about machines from studying brains, and much about brains from studying machines. He has thus always worked for an interdisciplinary environment in which computer scientists and engineers can talk to neuroscientists and cognitive scientists.

Professor Jeffrey L. Elman

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Professor Jeffrey Elman is a cognitive scientist with expertise in linguistics. He is Founding Co-Director of the Kavli Institute for Brain and Mind and Dean of Social Sciences at UC San Diego.

His primary research interests are on language processing and learning. He studies language both through computational models and also through psycholinguistic and neuroimaging studies.

In his early work, he was interested in speech perception, and what the mechanisms are that make it possible for humans to perceive complex acoustic inputs with such apparent ease.

International Partner Investigators

Professor John O'Keefe

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Professor John O'Keefe is a neurophysiologist and Fellow of the Royal Society who has extensive experience in all aspects of rodent navigation and its neural bases. His seminal book The Hippocampus as a Cognitive Map (O'Keefe and Nadel, 1978) underpins the empirical directions for the conceptual mapping research. He is at University College London.

Research Fellows

Daniel Angus, PhD

Daniel joined Thinking Systems as a research fellow studying navigation in conceptual spaces. He completed a Bachelor of Engineering (Electronics and Computer Systems) and a Bachelor of Science (Research and Development) as part of Swinburne University's Vice-Chancellors research scholarship program. Daniel's research interests include the design and application of Computational Intelligence techniques to difficult Engineering and Science problems, in particular those that contain high numbers of dimensions and conflicting objectives. In his PhD, 'Niching Ant Colony Optimisation', he studied the effect of population diversity on ant-inspired algorithm efficacy, completed at the Intelligent Systems Lab, Swinburne University, Melbourne.

David Ball, PhD

David Ball joined Thinking Systems as research fellow with particular focus on the engineering facets of the project. He holds a Bachelor of Computer Systems Engineering (Mechatronics) from The University of Queensland and completed his PhD in Mechatronics Engineering. David's research interests are in robots and agent systems for real dynamic, spatial environments. In particular, robot mobility for wheeled and legged robots, multi-agent coordination, control and navigation. David has held technical and organisational committee positions, including for the international event RoboCup. He has represented the University of Queensland five times at the international robot soccer competition, achieving second place twice.

Research Fellows

Oliver Baumann, PhD

Oliver obtained his Diploma (MSc.) in Psychology from the University of Oldenburg (Germany) in 2003 and his PhD from the University of Regensburg (Germany) in 2006. His doctoral thesis investigated the neural correlates of audio-visual motion perception and the role of the neocerebellum in eye movements. Then he spent one year as a postdoctoral fellow at the University of Oslo (Norway) under the supervision of Professor Svein Magnussen on the investigation of the neural correlates of perceptual memory. He is currently employed as a research fellow at the Queensland Brain Institute in Prof. Jason Mattingley's Cognitive Neuroscience Laboratory. His present research is on human navigation, with the focus on how human beings use and process visual landmarks for navigating successfully through a novel environment. The research methods used include the assessment of behavioural performance as well as neuroimaging techniques.

Allen Cheung, PhD

Allen completed his PhD at the Australian National University in December 2007. His research goals are to study of animal navigation using both top-down and bottom-up theoretical methods to understand specific and general principles of neuronal network function. Methods range from pure mathematical theory to closed-loop computer simulations of navigating agents with biologically plausible neuronal networks.

Tien Luu, PhD

Tien Luu joined Thinking Systems as a research fellow studying insect navigation. Previous post-doc experience was in ion channel electrophysiology. One aspect of this theme of the Thinking systems project is to record brain activity from honeybees during navigational tasks. Tien’s research experience is in electrophysiology of ligand-gated ion channels; point-mutagenesis in recombinant GABAA receptors. Her Thinking Systems research goal: electrophysiological recordings from live honeybees, looking at candidate cellular substrates of navigation systems.

Research Fellows

Michael Milford, PhD

Michael holds a PhD in Electrical Engineering and a Bachelor of Engineering from the University of Queensland, awarded in 2006 and 2002 respectively. He is currently a Postdoctoral Research Fellow in the School of Engineering Systems at the Queensland University of Technology, after previously working as a Research Fellow at the Queensland Brain Institute and in the Robotics Laboratory at the University of Queensland. His research interests include Simultaneous Localisation And Mapping, cognitive modelling of the rodent hippocampus and entorhinal cortex, and biologically inspired robot navigation.

Peter Stratton, PhD

Peter obtained his PhD in cognitive modelling with neural networks from the University of Queensland in 2002. He then worked in the software industry in Australia and the USA for several years before returning to academia in 2007, joining the Thinking Systems project. His research interests include models of spiking neurons and spiking neural networks, the hippocampus and cortex.

Francois Windels, PhD

Research Associate

Francois is a neuropharmacologist working as a Research Associate at the Queensland Brain Institute. He received his PhD from the University of Grenoble, France, in 2001. His research was focused on the mechanism of deep-brain stimulation used to improve Parkinson's disease symptoms. For that work he used animal models of Parkinson's disease, localised brain lesions, intracerebral microdialysis and high-pressure liquid chromatography. After completing his PhD, he moved to the National Institute on drug abuse where he worked for four years on neurotransmission in the basal ganglia and more specifically on the effects of dopamine using electrophysiology and microiontophoresis in freely behaving rats. Since 2006, he has worked with Professor Pankaj Sah at the Queensland Brain Institute on synaptic plasticity involved in emotional memory, a mechanism regulated by dopamine.

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Dr Claudianos obtained his PhD degree in Biochemistry and Molecular Biology from the Australian National University in 1999. Dr Claudianos went on to study 'malaria' development as NHMRC-funded CJ Martin Fellow at Imperial College, London, before returning to the Australian National University in 2002, where he worked on the mosquito and honeybee genome projects including the role of carboxyl/cholinesterase molecules in central nervous system synapses. Dr Claudianos was recruited to the Queensland Brain Institute in 2007.

Marcus Gallagher, PhD

Marcus Gallagher is a Senior Lecturer in the School of Information Technology and Electrical Engineering at the University of Queensland, Australia. He received his Bachelor of Computing Science and Graduate Diploma in Science from the University of New England, Australia in 1994 and 1995 respectively, and his PhD in 2000 from the University of Queensland, Australia. His main research interests are metaheuristic optimisation and machine learning algorithms, in particular techniques based on statistical modelling. He is also interested in biologically inspired algorithms, methodology for empirical evaluation of algorithms and the visualization of high-dimensional data.

Dhanisha Jhaveri, PhD

Originally from Mumbai, India, Dhanisha holds a PhD in biological sciences from Tata Institute of Fundamental Research, University of Mumbai, India awarded in 2003. She is currently a postdoctoral research fellow at the Queensland Brain Institute working with Professor Perry Bartlett's group. Her research interests include understanding molecular mechanisms regulating adult neural stem cells and gaining insights into the role of adult neurogenesis during learning and memory.

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Wei Luo received his PhD in Computer Science from Simon Fraser University, Canada. He is currently a Postdoctoral Research Fellow in the School of Information Technology and Electrical Engineering at the University of Queensland. His research interests include machine learning, data mining, information visualization, and their applications to healthcare.

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Angelique Paulk is a postdoctoral research fellow working with Bruno van Swinderen at the Queensland Brain Institute.

Judith Reinhard, PhD

Originally from Germany, Judith holds a PhD in biological sciences from the University of Bayreuth, Germany. She is currently a Senior Research Fellow at the Queensland Brain Institute, working in the Visual and Sensory Neurosciences Group. Judith research interests include understanding how animals detect, process, and use sensory information from their surroundings such as visual and olfactory cues, to successfully navigate their environment, forage for food and solve complex problems.

Ruth Schulz, PhD

Ruth was awarded a PhD from the University of Queensland in 2008. Her PhD work was part of the RatChat project and involved grounding a spatial language in mobile robots. She is currently a postdoc with the RatChat project, which is extending the language abilities of the robots. Her research interests include the evolution of language, spatial language, and developing a computational model of language for mobile robots.

Affiliates

Bruno van Swinderen, PhD

Dr Bruno van Swinderen received his PhD in Evolutionary and Population Biology in 1998 from Washington University in St. Louis, Missouri. His graduate work was on general anaesthesia in a Caenorhabditis elegans model, applying both quantitative genetics and molecular genetic approaches.

For his postdoc at The Neurosciences Institute (NSI) in San Diego, California (1999-2003), he switched to Drosophila melanogaster in order to develop methods of studying perception in the fruit-fly model. He ran a lab at NSI from 2003 to late 2007. In February 2008, Dr van Swinderen established a new laboratory at the Queensland Brain Institute.

PhD Students

Edgar Chan

Edgar Chan is a PhD candidate in the School of Psychology, under the supervision of Professor Jason Mattingley and Dr Mark Bellgrove. He completed his BA (Psychology) degree with first class Honours at Melbourne University in 2006, and was awarded the APS Prize. In addition to his research into human spatial navigation, Edgar is also undergoing professional training as a Clinical Neuropsychologist at UQ.

Chris Nolan

Chris Nolan is a PhD student in UQ's School of ITEE, focusing on biologically inspired robotics. He has received a Bachelor of Engineering (Computer Systems) and a Bachelor of Science (Computer Science) from the University of Queensland. Chris has spent five years in the software industry, working as a software developer and a technical consultant, primarily in the employ of Oracle Corporation..

Paul Stockwell

Paul has worked in the IT industry for fifteen years in many different sectors including the Manufacturing, Finance, Telecommunications and Insurance sectors and for such organisations as BHP, Suncorp and both state and local government before returning to commence his PhD full time at the beginning of 2007 on an Australian Postgraduate Award. He has significant real world experience and has worked in various roles, from Senior Analyst/ Programmer to Technical Architect and Software Development Manager. Paul is currently the Product Architect for TSA Software Solutions, where he is responsible for the technical direction of the company as well as researching technologies and methods for their enterprise-level commercial application suite. Paul holds a Bachelor of Information Technology with 1st class honours.

PhD Students

William Maddern

Will received his Bachelor of Engineering (Mechatronics, first class Honours) from the University of Queensland in 2008, and is currently a PhD candidate at the School of Engineering Systems, Faculty of Built Environment and Engineering, QUT. His area of research is biologically inspired robot navigation, and aims to combine characteristics of the RatSLAM system with traditional simultaneous localisation and navigation techniques. His research interests include biologically-inspired sensors and control, robot perception, field robotics and UAVs.

Gavin Taylor

Gavin Taylor completed a Bachelor of Engineering (Mechatronics) degree at UQ at the end of 2008 and following this completed a summer scholarship with Thinking Systems. As a result, he decided to continue his work during the summer by starting a PhD focusing on investigating visually guided honeybee flight behaviour. In addition to interests in mechatronic systems and robotics, he has developed an interest in biology, and would like to look at how biological systems can provide inspiration for novel robotic systems.

Affiliate PhD Students

Arren Glover

Arren recently graduated from the University of Queensland receiving a Bachelor of Engineering (majoring in Mechatronics and graduating with first class honours). He is currently a PhD candidate within the school of ITEE working on the RatChat project. His project centres on robot interaction with its environment and involves techniques in the fields of computer vision, probabilities and statistics, and machine learning.

Chris Lehnert

Chris holds a Bachelor of Engineering majoring in mechatronics from the University of Queensland, awarded in 2009. He is currently working on his PhD at the Queensland University of technology, which seeks to develop a learning control system that can adapt to the system model of an imprecisely manufactured robot. The research seeks to converge the biological knowledge of the motor cortex and cerebellum with the control theory domain of iterative learning control for robotic applications.

Alumni

Shervin Emami (ITEE, Robotics lab)

For the past 13 years I have programmed in C/C++, Java, Assembly language and VB for Windows, DOS & Linux. I have a Masters degree in Robotics, a BSc in Computer Science, and a BEng in Mechatronics Engineering. I have worked in Australia, USA and UAE (Dubai) on state-of-the-art robotics and computer vision technologies, from self-balancing robots that can climb stairs, to humanoid robots that can talk and recognize faces.

Tara Hamilton, PhD

My research activities involve low power analogue IC design, neuromorphic engineering (modelling neurons and neural systems), biomedical engineering, and electronics (basically anything with transistors!). I completed the BE (Electrical) Hons I and BCom (Economics and Marketing) in 2000 from the University of Sydney. In 2000 I began working at Cochlear Ltd. first as a Quality Engineer and then as an IC Design Engineer. I started my PhD in 2004 and also worked as a consultant for a number of companies including: Cochlear Ltd., Surgical Diagnostics Pty. Ltd., G2microsystems and Perceptia Design Services. I was awarded a PhD from the University of Sydney in 2008. In 2008 I started at the University of Queensland as a lecturer in Electronics.

David Prasser, PhD

David Prasser's work was part of the RatSLAM project, a biologically inspired solution to Simultaneous Localisation and Mapping. During this work he was mostly involved in RatSLAM's visual processing system, which was the subject of his submitted thesis. In 2007 he was a postdoc with the RatCHAT project, which added language capabilities to RatSLAM, and also lectured UQ's course on Control Systems and Robotics. His main research interests are in the areas of biologically and cognitively inspired robotics.

Alumni

Mark Wakabayashi

Mark is a software engineer with Bachelor degrees in Arts (majoring in Cognitive Science) and Information Technology (with Honours). While studying, he worked in several positions as a research assistant in bioinformatics, biological modelling and visualisation, and robotics. After graduating he joined Thinking Systems in 2007 as Systems Engineer, developing and re-engineering software as well as providing software support. In 2008 Mark moved to London and has worked with a number of research oriented commercial companies.

Student Research Scholars

Elizabeth Alpert

ITEE Summer Scholar (2008-09), (2009-10), (2010-11)

Betsy is starting her final year of a Bachelor of Information Technology/ Bachelor of Arts. She studies linguistics, history (classical and medieval), and whichever computing courses take her fancy. She enjoys interactions between different areas of knowledge, and is particularly interested in combining linguistics and computing to deal with issues of artificial systems and natural language usage and comprehension.

Hilton Bristow

ITEE Summer Scholar (2009-10)

Hilton is currently studying as a fourth-year Engineering student, majoring in Mechatronics. His summer project at Thinking Systems involved porting a SLAM navigation algorithm to an omnidirectional drive platform, and helped instil his interest in biologically inspired robotics. His thesis continues in a similar vein, and explores the viability of using the GPU as a coprocessor in computationally demanding aspects of SLAM.

Nick Calver

ITEE Summer Scholar (2009-10)

Nick is entering his final year of a Bachelor of Engineering, majoring in Mechatronics. He is interested in biomimetic systems of all kinds, especially prosthetics. He is fascinated with human-machine integration and hopes cyborgs will one day be commonplace. During his time with Thinking Systems, he researched and prototyped a whisker sensor to be used on a robot rat.

Daniel Clarke

ITEE Summer Scholar (2009-10)

Daniel Clarke is about to commence the fourth year of his degree, an extended major in Mechatronic Engineering. His main interests lie in embedded systems, the control of autonomous vehicles and biomimicry. Over the summer he worked on an outdoor robot platform used for navigational experiments.

Scott Heath

ITEE Summer Scholar (2009-10); Research Assistant 2010.

Scott is currently in his fifth year of a dual Electrical Engineering/IT degree. He has an interest in software design in general, in particular game/simulation design and also web server development. He worked for Thinking Systems over summer, designing a web interface for their Pioneer robots so they would be publically accessible from the internet.

Andrew Jones

ITEE Summer Scholar (2008-09)

Andrew Jones graduated at the end of 2009 in Engineering (Mechatronic) / Arts (German and Mathematics) dual degree. His undergraduate thesis is on the Visualisation High Dimensional Data, in particular data that is derived from text. He is interested in Computational Linguistics and non-linear optimisation techniques among other Artificial Intelligence topics.

Steven Langsford

ITEE Summer Scholar (2007-08)

Steven completed a degree in Psychology at Adelaide University and with honours in 2009. Along the way, he managed to pick up a diploma in translation (Chinese) from TAFE SA, some experience as a research assistant for Dr Simon Dennis, and an interest in all things cognitive or language-y. He received a scholarship to study for his PhD in China in 2009.

Timothy Martin

QBI Summer Scholar (2009-10), Research Assistant 2010.

Tim is currently in his third year of a Bachelor of Engineering (mechatronics). He is interested in the robust skill set of mechatronic engineering and its integration into society. Over the summer, Tim aided in the Thinking Systems research by automating and streamlining experiments conducted by research staff at the Queensland Brain Institute, using software engineering and computer vision techniques.

Joel McGrath

ITEE Summer Scholar (2009-10)

Joel is currently completing his final year of his undergraduate degree of Mechatronic Engineering. He is currently employed by the Royal Australian Air Force, taking part of the Undergraduate Sponsorship Program. He hopes to apply skills learnt within his degree for his future career for both research and development. Over the summer, he developed an initial stage for an omni-direction machine vision system.

Kieran McLean

ITEE Summer Scholar (2009-10)

Kieran is currently commencing his final year in a Mechatronic Engineering degree. He is interested in control systems engineering and computational modelling. Over the summer he has worked for Thinking Systems at The Queensland Brain Institute. His focus was on using computational techniques to help understand the impact of sensor and motor noise in the path integration of mammals, in the hope a similar process could be implemented on their Pioneer robots.

Timothy Mews

ITEE Summer Scholar (2008-09)

Tim is currently in his second year of a double degree in Engineering and Science at the University of Queensland. His engineering majors are Mechanical and Aerospace, with a Physics major for the Science degree. These choices stem from his long-time interests in the fields of flight and aerodynamics, as well as his ongoing curiosity in how mechanical systems work.

Robert Ninness

ITEE Summer Scholar (2008-09)

Robert holds a Bachelor of Multimedia Design and is currently completing a Bachelor of Science. He is interested in merging the media skills he has learnt while studying multimedia design, with a general science background. Currently he is involved with micro-fabrication of hardware used in electrophysiology experiments.

Trang Nguyen

ITEE Summer Scholar (2009-10)

Trang Nguyen is in her final year of a Bachelor of Engineering, major in Biomedical and Electrical Engineering. Her interests include complex biological systems, biomedical signals and image processing, electronics and dynamic systems. This summer Trang conducted research on hippocampus modelling to extract interesting behaviours from a complex dynamic system using spiking neuronal network.

Jack Valmadre

ITEE Summer Scholar. Research Assistant

Jack Valmadre is working on his Engineering thesis on' 3D Human Pose Estimation using Rigid Structure' at UQ. His interest in robotics began when he competed in the RoboCup Junior competition at school. He recently completed an internship at Microsoft working in their internet search division, Live Search.

Ryan Wong

ITEE Summer Scholar (2008-09)

Ryan is in his fifth year of a dual degree in Engineering (Mechatronics) and Commerce (Finance) at the University of Queensland (UQ). He is currently pursuing an undergraduate thesis with Thinking Systems, developing a multichannel wireless neural recording and video tracking system suitable for rat navigation. His academic interests include digital systems, electrophysiology and wireless technologies.

Jessica Wrigley

ITEE Summer Scholar (2009-10)

Jessica is a completing her fourth year of Mechatronic Engineering. During summer 09/10 she worked on developing a new motor driver system for the Omni-directional robot. Through this project she has learnt about different microcontrollers, motor controllers and integrated development environments. She is very interested in mathematical and dynamic modelling and hopes to develop robotic legs for the Robo-Rat for her undergraduate thesis.

Kieran Wynn

ITEE Summer Scholar (2009-10)

Kieran is in his final year studying Mechatronics Engineering at UQ. He enjoys working with embedded systems, hardware design and low-level software, particularly in taking promising new technologies and adapting them for use in robotic applications. Over summer he researched and designed a battery powered supply and recharging system for a fully autonomous omni-directional robot as well as exploring options for a cross-platform recharging dock system for mobile robots.

Ezra Zigenbine

ITEE Summer Scholar (2009-10)

Ezra is a fourth year undergraduate studying Mechatronics engineering at the University of Queensland.

Ezra's role at Thinking Systems during the summer break of 2009-2010 was to research and develop a robust sensor system for an omni-directional robot. This included not only proximity sensing but haptic and cliff detection as well.