UTS Unleashed! Team Description

1. Research Interests

Our research is multidisciplinary and focuses on several important aspects of robotics. In particular, we have special interests and extensive expertise in the following areas:

- Knowledge Representation and Reasoning
- Cognitive Robotics and Reasoning about Action
- Intelligent Information Integration
- Embedded Systems and Agent Technologies
- Modeling and control of complex mechanical systems
- Navigation and Control of Multiple Mobile Robots,
- Sensor Fusion

2. Proposed Approach to address the RoboCup challenge

Our major interest in the RoboCup Challenge lies in designing and developing expressive and robust world knowledge, and effective robot soccer strategies. We are also interested in building a robot soccer team that *knows* it is playing soccer!

Our research objectives are twofold: first to apply intelligent techniques in the 4-legged robot league domain [7], and second to use this domain as a test bed to develop solutions for wider application in other complex domains [1,2,3].

We have successfully built a powerful and flexible development environment that provides essential infrastructure for constructing methods and algorithms for the necessary robot soccer abilities; locomotion, localization, behaviours, skills, and actions (e.g. kicks). Using this infrastructure we are able to develop specialized robot soccer players (e.g. forwards, goalies etc). Our system uses a proactive *sense-think-act cycle* which is built on a 4-layer Agent Architecture: Perception, Conceptual, Deliberation, and Communication. We have also built a number of useful AIBO Management Tools to support a wide range of activities including: the simulation of body movements, vision calibration, soccer strategies, and debugging.

The 4-legged robot league domain provides a rich environment for us to explore deep and fundamental issues related to perception, high level deliberation and communication.

For an agent to be successful, in even moderately, complex environments they require a concept modeling and management component. Concept management is particularly important if the agent needs to interact and communicate with other agents. In order for agents to communicate effectively they must share concepts, and attribute the same meaning to those shared concepts.

One topical and exciting research interests of our team concerns how symbols used in high level reasoning are *grounded* in percepts [3] where we use a computationally effective representation of a multidimensional conceptual space as our modeling tool [2]. We organized a *Workshop on Grounding Robot Sensory Information and Symbolic Knowledge*[1] in February 2003 which focused the problems related to sensory fusion and grounding. Grounding sensory and symbolic

[1] http://research.it.uts.edu.au/magic/grounding/

information in robots involves linking the internal representation of the world to real world objects. Grounding is an important issue in all agents from rodents to primates.

Conceptual spaces [2,3] provide the infrastructure for linking the perception and the deliberation layers, in other words they provide mechanisms for integrating information gained from sensors with higher level strategic knowledge for reasoning. The solutions that need to be developed for soccer playing robots must be fast, effective and suitable for a limited processing power on the AIBO which during the course of a soccer match must react quickly and not spend long periods of time deliberating on the best strategy, or building the best plan. To this end we have been exploring the use of game plays and case-based reasoning [4].

Mobile robots need to adapt to changes in their environments and to improve their performance over time. To improve the performance of the robot soccer playing behaviour we are exploring various techniques in machine learning [5] and adaptive control [1] which fit quite naturally into the conceptual space framework, and can range from simple to highly sophisticated mechanisms a crucial design element for extensibility and wide applicability.

We are building on the extensive research work and achievements by numerous research groups and teams already reported [7]. We also gained tremendously by being the leaders in the NUbots in 2002, and as such have been able to develop a vastly improved and completely new architecture, new walk, new localization, new behaviours. Furthermore, we are in the process of developing our new system even further. For example, we are developing an algorithm to build an extended world model to be shared among the puppies that contains information about the location of the team, opposition and the ball. The key challenge is to design a statistically consistent algorithm that can operate even when communication among the puppies is intermittent. A combined decentralized information fusion filter and particle filter to address this issue is being developed.

In summary we have built on the strengths of our previous experience with the highly successful NUbots and have developed an entirely new and innovative robot soccer system based on a multiagent architecture that brings together techniques from cognitive robotics, knowledge representation and reasoning, machine learning, computational geometry, and probabilistic methods under the unifying conceptual spaces framework so that our techniques can be extended to mobile robots operating beyond the limits of the constrained soccer-field environment.

1. **Gamini Dissanayake**, P. Newman, H.F. Durrant-Whyte, S. Clark, M. Csobra, A solution to the simultaneous localisation and map building (SLAM) problem, IEEE Transactions on Robotics and Automation, 17(3), 229-241, 2001.
2. Peter Gärdenfors and **Mary-Anne Williams**, Reasoning about Categories in Conceptual Spaces, in the Proceedings of the Seventeenth International Joint Conference on Artificial Intelligence, Morgan Kaufmann, 385 - 392, 2001.
3. Peter Gärdenfors and **Mary-Anne Williams***, Building Rich and Grounded Robot World Models from Sensors and Knowledge Resources: A Conceptual Spaces Approach*, in the Proceedings of the 2nd International Symposium on Autonomous Mini-Robots for Research and Edutainment, 34 – 45, 2003.
4. **Alankar Karol**, Bernhard Nebel and **Mary-Anne Williams**, Case Based Game Play in the RoboCup Four-Legged League: Part I The Theoretical Model, submitted to the RoboCup 2003 Symposium.
5. J. Lee. and **Mary-Anne Williams**, *Multi-Level Clustering and Reasoning about Clusters using the Region Connection Calculus*, in Proceedings of the Seventh Pacific-Asia Conference on Knowledge Discovery and Data Mining, 2003 (in press).
6. Manuela Veloso, Williams Uthwe, Machahiro Fujita, Minoru Asada and Hiroaki Kitano (eds) Playing Soccer with legged ronbots", in the proceedings of the international conference on Intelligence Robots and Systems, 437 – 442, 1998.
7. RoboCup-98: Robot Soccer World Cup II – RoboCup-2002: Robot Soccer World Cup V Series, Springer Verlag, Notes in Artificial Intelligence, 1999 – 2002.
8. Stephan Chalup, Nathan Creek, Leonie Freeston, Nathan Lovell, Josh Marshall, Rick Middleton, Craig Murch, Michael Quinlan, Graham Shanks, **Christopher Stanton**, & **Mary-Anne Williams**, When NUbots Attack! 2002 NUbots Team Report, http://research.it.uts.edu.au/magic/NUbotFinalReport.pdf

3. Background of the Principal Investigator

Mary-Anne Williams (Team Leader) holds a *Research Chair* at the University of Technology, Sydney and directs the *Innovation and Technology Research Laboratory* in the Faculty of Information Technology.

She has been working in Artificial Intelligence for over twelve years, and has over 80 refereed publications in the area. Her primary focus is on Knowledge Representation and Cognitive Robotics and has contributed to theory and practice, as well as demonstrated its power in a wide range of real world applications. Her main contribution has been the development of theoretically sound computational models for belief revision and general iterated belief revision which can be implemented effectively with anytime algorithms.

Mary-Anne was *Team Leader* of the NUbots; the University of Newcastle Team that entered the league in 2002 and came third in the RoboCup Four-Legged League Soccer Competition and RoboCup Four-Legged Challenge in 2002. The NUbot Team report[2] is available.

Mary-Anne's PhD was awarded *Best Australian PhD Dissertation in Computer Science Award* from the Computer Science Association in 1994. She has also received several other wards, e.g. a *Commonwealth Fellowship* awarded by the *Australian Academy of Science*, and a *British Council Fellowship*.

Mary-Anne's main research interests are in Knowledge Representation, Belief Revision, Concept Learning, Cognitive Robotics, Symbol Grounding in Robots, Agent Technologies, Software Engineering and Embedded Systems.

Mary-Anne is Conference Chair of Ninth International Conference on Principles of Knowledge Representation and Reasoning (KR2004) http://research.it.uts.edu.au/magic/KR2004, and was Program Co-Chair of the Eighth International Conference on Principles of Knowledge Representation and Reasoning (KR2002). She served on the Advisory Board and the Program Committee for IJCAI'01. She is Workshop Chair for IJCAI'03. She has organized a large number of highly successful events related to Cognitive Robotics and Knowledge Representation, a Cognitive Robotics Workshop at IJCAI'01 where Dieter Fox from the University of Washington gave an invited talk on probabilistic algorithms for navigation and localization in mobile robots. She has also served on numerous program committees e.g. JELIA-03, ECSQARU-03, IJCAI-01, JELIA- AAAI-98, AAAI-99, IJCAI-01, ECAI-99, KR-98. She has been Chief Investigator on five Australian Research Council Discovery Projects in the area of Knowledge Representation and Cognitive Robotics including one that focuses on the use of Conceptual Spaces and Robot Communication. In addition Mary-Anne supervises several Robotics Projects and several students working on robotics applications. She has a strong track record in research leadership having established the *Newcastle Robotics Laboratory* at the University of Newcastle in 2001, and the *Innovation and Technology Research Laboratory* at the University of Technology Sydney in 2002. Before moving to the University of Technology Sydney in 2002 she was *Assistant Dean (Research*) in the Faculty of Business and Law, and served on the *University's Research Portfolio Committee*.

Mary-Anne has developed solid international links and joint research projects with prestigious research groups: e.g. CNRS (France), Stanford, MIT, Lund University (Sweden). She has been an invited speaker at several international and national conferences, workshops, and doctoral seminar series. She has also co-edited a book "Frontiers in Belief Revision" published with Kluwer in 2001, a special issue on Commonsense Reasoning for S*tudia Logica: An International Journal on Symbolic Logic* in 2002. Based on a recent AAAI Spring Symposium she will co-edit a special issue of the Knowledge Base Systems Journal with John McCarthy (Stanford) and Patrick Doherty (Linkoping, Sweden).

4. Description of the team organization and effort to be spent

UTS Unleashed! is a strong and highly dedicated team consisting of two full Professors, two Post-Doctoral Fellows, one PhD student, and eight high distinction average 4th year Undergraduate Students studying Software Engineering and Computer Science.

The team has significant research strengths in robotics, and is highly committed to building an innovative high performance robot soccer multi-agent system. All members of the team will play an active role in developing algorithms for the legged robot team. The team's home base is in the *Innovation and Technology Research Laboratory*; a new facility in the Faculty of Information Technology at the University of Technology Sydney which is a specialized research space that consists of a competition soccer field, a network of 9 workstations, 9 AIBOs, and reconfigurable halogen lights.

Professor Mary-Anne Williams: UTS Unleashed! Team Leader – see description in Section 3 above.

Professor Gamini Dissanayake in the Faculty of Engineering at the University of Technology is well known in the area of robotics. He has received five Australian Research Council Projects and has published more than 100 papers in robotics. He led the Simultaneous Localisation and Map-building (SLAM) research at the Australian Centre for Field Robotics until the end of 2001 when he moved to UTS. Under his leadership this group made significant theoretical and

[2] http://research.it.uts.edu.au/magic/NUbotFinalReport.pdf

experimental progress and is now recognized as a world authority in this area. He was the first to develop a technique to exploit the constraints governing the motion of a land vehicle for computing the location of a vehicle from the measurements of inertial navigation units. He has also made significant contributions in the areas of control and high speed positioning of dynamic systems and in the area of cargo handling where he is a co-inventor in a world-wide patent on a novel retrieving arrangement for container handling cranes.

Dr Alankar Karol: is a Post-Doctoral Fellow in the Innovation and Technology Research Laboratory. He has a PhD in Applied Mathematics and a Master of Mathematical Finance. Alankar's main research interests are in mathematical modeling. He has developed our localization model together with Gamini.

Dr Suku Sinna: is a Post-Doctoral Fellow in the Innovation and Technology Research Laboratory. He has a PhD in Information Systems. Suku's main interests are in Conceptual Spaces and Knowledge Representation.

Christopher Stanton: is a PhD Student. Chris was one of the main contributors to the success of the NUbots in 2002. The NUBots used Chris' strategies and positional play behaviour to come third at RoboCup 2002. The three key students in the NUbot team were Chris, Michael Quinlan and Craig Murch. Michael and Craig are part of the NUbot 2003 team. Chris received First Class Honours on the basis of his significant contributions to the NUBots in 2002. His Honours thesis was in the area of grounding sensory information.

Nicholas Agnew, Peter Brownlow, Shannan Heinitz, Peter Horsley, Yohan Hartanto, David Morris-Oliveros, Michael Trieu, and **Astrid Zeman** are Undergraduate Students working in the team. These students have excellent academic records - all have achieved a High Distinction Average – and were selected for the team on a competitive basis.

5. Pointers to relevant publications

1. **Christopher Stanton** and **Mary-Anne Williams**, Grounding Robot Sensory and Symbolic Information in the Semantic Web, submitted to the RoboCup 2003 Symposium.
2. **Alankar Karol**, Bernhard Nebel and **Mary-Anne Williams**, Case Based Game Play in the RoboCup Four-Legged League: Part I The Theoretical Model, submitted to the RoboCup 2003 Symposium.
3. Tomonari Furukawa, Hugh F. Durrant-Whyte, **Gamini Dissanayake** and Salah Sukkarieh, "The Coordination of Multiple UAVs for Engaging Multiple Targets in a Time-Optimal Manner", Submitted to 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems.
4. Pavlos Peppas, Gianni Tselekidis, and **Mary-Anne Williams**, Knowledge Management, Dynamic Capabilities and Sustained Competitive Advantage, **Journal** of the Operational Research Society, in press.
5. Peter Gärdenfors and **Mary-Anne Williams**, *Building Rich and Grounded Robot World Models from Sensors and Knowledge Resources: A Conceptual Spaces Approach*, in the Proceedings of the 2nd International Symposium on Autonomous Mini-Robots for Research and Edutainment, 34 – 45, 2003.
6. Ickjai Lee. and **Mary-Anne Williams**, *Multi-Level Clustering and Reasoning about Clusters using the Region Connection Calculus*, in Proceedings of the Seventh Pacific-Asia Conference on Knowledge Discovery and Data Mining, 2003 (in press).
7. S.B. Williams and **Gamini Dissanayake**, "An Introduction to Mobile Robotics", In *Handbook of Manufacturing*, Ed. D.T. Pham, Springer-Verlag, (*in press*)
8. Tomonari Furukawa, Hugh F. Durrant-Whyte and **Gamini Dissanayake**, "Time-Optimal Cooperative Control of Multiple Robot Vehicles", To be presented at IEEE International Conference on Robotics and Automation, May 2003.
9. Stephan Chalup, Nathan Creek, Leonie Freeston, Nathan Lovell, Josh Marshall, Rick Middleton, Craig Murch, Michael Quinlan, Graham Shanks, **Christopher Stanton**, and **Mary-Anne Williams**, When NUbots Attack! The 2002 NUbots Team Report, http://research.it.uts.edu.au/magic/NUbotFinalReport.pdf
10. Salem Benferhat, Didier Dubois, Henri Prade, and **Mary-Anne Williams**, A Practical Approach to Fusing Prioritized Knowledge Bases, *Studia Logica An International Journal for Symbolic Logic,* Kluwer, 70(1): 105-130, 2002.
11. Wei Liu and **Mary-Anne Williams**, *Trustworthiness of Information Sources and Information Pedigree,* Intelligent Agents VIII, Series: Lecture Notes in Computer Science. Volume 2333: 290 – 306, 2002.
12. **Gamini Dissanayake**, S.B. Williams, H. Durrant-Whyte, T. Bailey, "A computationally efficient solution to the simultaneous localisation and map building (SLAM) Problem", Autonomous Robots, 12, 267-278, 2002.
13. **Mary-Anne Williams** and Hans Rott, Frontiers in Belief Revision, Kluwer, 2001.
14. Salem Benferhat, Souhilla Kaci, Daniel Le Berre, and **Mary-Anne Williams**, Weakening Conflicting Information for Iterated Revision and Knowledge Integration, in the Proceedings of the Seventeenth International Joint Conference on Artificial Intelligence, Morgan Kaufmann, 109 - 115, 2001.
15. Peter Gärdenfors and **Mary-Anne Williams**, Reasoning about Categories in Conceptual Spaces, in the Proceedings of the Seventeenth International Joint Conference on Artificial Intelligence, Morgan Kaufmann, 385 - 392, 2001.
16. Wei Liu and **Mary-Anne Williams**, A Framework for Multi-Agent Belief Revision, Studia Logica, vol. 67(2), 219 - 312, 2001.
17. Pavlos Peppas, Costas Koutras, and **Mary-Anne Williams**, Prolegomena to Concise Theories of Action, Studia Logica, vol. 67(3), 403-418, 2001.
18. **Gamini Dissanayake**, P. Newman, H.F. Durrant-Whyte, S. Clark, M. Csobra, A solution to the simultaneous localisation and map building (SLAM) problem, IEEE Transactions on Robotics and Automation, 17(3), 229-241, 2001.
19. **Gamini Dissanayake**, S. Sukkarieh, E. Nebot, H. Durrant-Whyte, The aiding of a low cost, strapdown inertial unit using modelling constraints in land vehicle applications, IEEE Transactions on Robotics and Automation, 17(5), 731-747, 2001.

20. S.B. Williams, **Gamini Dissanayake** and H.F. Durrant-Whyte, Towards Terrain-Aided Navigation for Underwater Robotics, RSJ Advanced Robotics, Vol. 15(5), pages 533-550, 2001
21. **Gamini Dissanayake**, and G. Fang, Minimum-time trajectories for reducing load sway in quay-cranes, Engineering Optimization, 33, 643-662, 2001.
22. G. Dissanayake, P. Newman, H.F. Durrant-Whyte, S. Clark, and M. Csobra, "An experimental and theoretical investigation into simultaneous localisation and map building (SLAM)". In *Lecture Notes in Control and Information Sciences, Experimental Robotics VI,* Springer–Verlag, 265-274, 2000.
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24. **Gamini Dissanayake** and S. Scheding, E. Nebot and H. Durrant-Whyte, "Autonomous Navigation of an Underground Mining Vehicle". IEEE Transactions on Robotics and Automation, 15(1), Feb. 1999, pp.85-95.
25. **Gamini Dissanayake**, M. Hebert, A. Stentz and H. Durrant-Whyte, "Map building and terrain aided localisation in an underground mine". In *Field and Service Robotics,* Springer-Verlag, 40-45, 1998.
26. Antoniou, G. and **Mary-Anne Williams**, Reasoning with Incomplete and Changing Information*, Journal Information Science,* 99, 1 & 2: 83 - 99, 1997.
27. **Gamini Dissanayake**, Neural network based distance functions for robot obstacle avoidance, Journal of Systems Engineering, 1, 1-8, 1993.
28. G. Fang, **Gamini Dissanayake**, Experiments on a neural network based method for time-optimal trajectory planning, *Robotica,* 16(2), 143-58, March-April 1998.
29. S. Scheding, **Gamini Dissanayake**, E. Nebot, H. Durrant-Whyte, "Autonomous Navigation of an Underground Mining Vehicle". *IEEE Transactions on Robotics and Automation,* 15(1), 85-95, 1999.
30. **Mary-Anne Williams**, Towards a Practical Approach to Belief Revision: Reason-Based Change, Luigia Carlucci Aiello and C. Shapiro (eds), Proceedings of the Fifth International Conference on Principles of Knowledge Representation and Reasoning, Morgan Kaufmann Publishers, 412 - 421, 1996.
31. **Mary-Anne Williams**, A Commonsensical Approach to Belief Revision, in the Proceedings of Fourth Symposium on Common Sense, 245 - 262, Stanford University, 1996.
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33. Grigoris Antoniou, Allan Courtney, Jorge Ernst, **Mary-Anne Williams**, A System for Computing Constrained Default Logic Extensions, in the Proceedings of the Fifth European Workshop on Logics and Artificial Intelligence, Lecture Notes in Artificial Intelligence, Springer Verlag, 1126: 237 - 250, 1996.
34. **Mary-Anne Williams**, Iterated Theory Base Change: A Computational Model, in the Proceedings of the Fourteenth International Joint Conference on Artificial Intelligence, Morgan Kaufmann Publishers, San Francisco, 1541 - 1550, 1995.
35. M. Pagnucco, N. Foo, B. Sims, and **Mary-Anne Williams**, Determining Explanations using Transmutations, in the Proceedings of the Fourteenth International Joint Conference on Artificial Intelligence, Morgan Kaufmann Publishers, San Francisco 822 - 830, 1995.
36. **Mary-Anne Williams**, Changing Nonmonotonic Inference Relations, in the Proceedings of the Second World Conference on the Foundations of Artificial Intelligence, Angkor, Paris, France, 469 - 480, 1995.
37. Grigori Antoniou, Kevin Wallace and **Mary-Anne Williams**, An Object-Oriented Implementation of Belief Revision, with in the Proceedings of the Eighth Australian Joint Conference on Artificial Intelligence, World Scientific, Singapore, London, 259 - 266, 1995.
38. **Mary-Anne Williams**, Conditionalizing Expectations, in the Proceedings of the Third Australian and New Zealand Conference on Intelligent Information Systems, 111 - 116, IEEE press, Perth, 1995.
39. **Mary-Anne Williams**, Changing Information States in Intelligent Information Systems, Australian Journal of Intelligent Information Processing Systems, 2: 20 - 27, 1995, (invited paper).
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41. P. Peppas, N.Y. Foo**, Mary-Anne Williams**, On the Expressibility of Propositions, *Logique et Analyse*, 251 - 272, 1995.
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43. **Mary-Anne Williams**, On the Logic of Theory Base Change, Logics in Artificial Intelligence, Lecture Note Series in Computer Science No 838, Springer Verlag, 86 - 105, 1994.
44. **Mary-Anne Williams**, Explanation and Theory Base Transmutations, in the Proceedings of the European Conference on Artificial Intelligence, Wiley Publishers, 341 - 346, 1994.

6. Statement of commitment to enter RoboCup-2003 in Padova, including traveling expense and registration fee for participation.

The UTS Unleashed RoboCup Team is a major joint initiative of the Faculty of Information Technology and the Faculty of Engineering at the University of Technology Sydney. The two Faculties will fund the team to RoboCup 2003 in Italy. We have secured funds to support travel and accommodation for a minimum of seven team members. When we have qualified we will attempt to attract sponsorship to support additional student travel. We have not approached any commercial sponsors yet, but plan to do so once we have qualified.